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Insect flower visitors in native plantings within the arable landscape of the Canterbury Plains

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A Dissertation

submitted in partial fulfilment

of the requirements for the Degree of

Masters in Agricultural Science

at

Lincoln University

by

Franziska Gabriela Schmidlin

Lincoln University

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Leiproctus fulvescens on *Veronica salicifolia*

Abstract of a Dissertation submitted in partial fulfilment of the

requirements for the Degree of Masters in Agricultural Science.

Abstract

Insect flower visitors in native plantings within the arable landscape of the Canterbury Plains

by

Franziska Gabriela Schmidlin

This thesis investigates the value of native plantings for pollination services within the arable landscape of Mid-Canterbury, New Zealand. The vegetation of the Canterbury Plains is among the most heavily modified landscapes in New Zealand with almost all original native vegetation replaced by intensive dairy and arable farming. Arable farmers often grow a variety of vegetable or herbage seed crops that depend on insect pollination. These include carrot, radish, onion, brassicas, and white and red clover.

Intensive crop farming on the Canterbury Plains can therefore be highly dependent on a good provision of insect pollinators to maintain economically viable yields. This study provides new insights into the abundance and diversity of insect flower visitors in native plantings established on arable farms. These plantings contain long-lived perennial plant species indigenous to the Canterbury Plains. There is currently strong interest in diversifying the pollinator communities in cropping farmland to reduce the risks associated with dependency on honeybees and bumblebees. Pollinator diversity and abundance may possibly be increased by providing habitats of native tree plants along crop margins that provide pollen and nectar resources, shelter, nesting or sites suitable for immatures to develop.

The aim of this thesis was to assess insect flower visitation in native plantings and the movement of these visitors into the arable fields at three sites five years post-establishment. Weekly standardised surveys of flower visitors were conducted between September 2017 and February 2018. Of all

observed flower visitors within the native plantings (n=3088 insects from 37 taxa), the most common were the honey bee, *Apis mellifera* (19.2 %) followed very closely by the native bee, *Lasioglossum* sp. (17.2%) and the native large hover fly, *Melangyna novaezealandiae* (14.8%). Other common dipteran species were the brown blow fly *Calliphora stygia* and the March fly *Dilophus nigrostigma* (both 7.1%) followed by the blue blow fly *Calliphora vicina* (7%), while native bees *Leioproctus* spp. (5.6%) were also well represented. A slight majority of all flower visitors were natives (52%).

All of these abundant insect flower visitors (at the taxa level assessed) were flower generalists, visiting five or more of the eight study plant species and the top eight are all recognised crop pollinators in New Zealand. While generalists, each species had different plant species preferences, different patterns of seasonal activity, and different responses to weather conditions. Results assessing the dispersal of insects from the native plantings into the crop field found that some (e.g. *Melangyna novaezealandiae, Lasioglossum sordidum)* were capable of moving distances of at least 250 m into neighbouring fields.

In combination, my results suggest that native plantings are capable of supporting a diverse and abundant community of insect flower visitors, including many crop pollinators, some of which travel at least hundreds of metres from these plantings. These plantings therefore have the potential to complement and reinforce pollination services from commercial bee hives. Further research is encouraged to better understand interactions between native plantings and the services they can provide to support insect crop pollination. Particularly important will be studies on pollinator food requirements, nesting resources, the capability of insect movement and quantification of influence on crop yield including pollination effectiveness and efficiency.

Keywords: agriculture, ecosystem services, pollination, native habitats, crop pollination.

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An earlier version of Chapter 3 of this thesis has been published and been presented to New Zealand Plant Protection society.

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Chapter 1

Introduction

1.1 Worldwide pressure on pollination

A decline in insect pollination services to crops threatens to have significant impacts on the variety and availability of foods that are currently consumed globally (Biesmeijer et al., 2006; Nabhan, 1998; Potts et al., 2010). Thirty-five percent of all food we eat relies on animal-mediated pollination; however 75% of the world's crops benefit from animal pollination (Klein et al., 2007) with increased size and quality of the harvest. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) estimated, in its 2017 Report on Pollination and food production, that the annual value of worldwide crops that are directly affected by pollinators is US$235 billion to $577 billion (Karbassioon, 2017).

The consequence of a pollinator decline has researchers warning of yield reduction or possibly failure to set seed altogether in some crops (Garibaldi et al., 2013; Klein et al., 2007; Kremen, Williams, & Thorp, 2002). Along with the mounting evidence of worldwide declines of pollinator taxa in agricultural landscapes (Biesmeijer et al., 2006; Hallmannet al., 2017; Potts et al., 2010), current crop-pollination services may be impacted with flow on implications for global food security. A reduction in pollinators could not only see a shortage of particular foods but have consequences for health through deficiencies of micronutrients (Smith et al., 2015). More than 90% of vitamin C , all Lycopene, almost all of the antioxidants (b-cryptoxanthin and b-tocopherol), the majority of the lipid, vitamin A and related carotenoids, calcium and fluoride, and a large portion of folic acid consumed be humans is contained in plants that depend fully or partially on animal pollination (Eilers et al., 2011).

Observed declines in wild and managed pollinator populations have been attributed to a combination of causes including increased use of pesticides and agrochemicals (Brittain & Potts, 2011; Van der Sluijs et al., 2013), intensification of agricultural production (Breeze et al., 2014) , introduced pathogens and parasites e.g. *varroa* mite (Cameron et al., 2011; Steffan-Dewenter et al., 2005) and the loss of habitats and forage options (Goulson et al., 2015; Potts et al., 2010).

While many researchers claim that species declines are based on human activity, long-term monitoring changes of local-scale insect biodiversity is globally uncommon and inconsistent (Vellend et al., 2017). A recent synthesis of time-series data suggests declines of species richness are dependent on locality, with pollinator diversity and abundance decreasing in some locations while stable or increasing in others (Cardinale et al., 2018). Discussion around the state of pollinators'

decline are ongoing; some studies examining changes in global pollinator abundance did not find enough evidence (Aizen et al., 2008) while other researchers have questioned whether a pollinator crisis exists as such (Ghazoul, 2005).

However, in some locations, there is evidence for a massive failure of fruit production. For example, in the Sichuan Province in China, 40,000 people now carry out pollination by hand on apple trees (O'Toole, 2013). For most of the world though, boosting pollination by renting honeybee colonies during the crop blooming time is the most common way to obtain commercial fruit yields. Worldwide the honey bee industry (pollination and honey production) has increased by 45% since 1961, but the area of pollination-dependent crops has increased more than 300% (Potts et al., 2010). This reliance on commercial honey bee hives is a substantial change. In past centuries crop pollination was available cost-free to human communities (Delaplane & Mayer, 2000), provided by wild pollinators including wild honey bees, native bees, flies, wasps, moths, butterflies and beetles (Lentini et al., 2012; Rader et al., 2009). A healthy and diverse wild pollinator community can both supplement commercial honey bee hives and provide natural insurance against a potential reduction and availability of managed pollinators.

In recognition of the pollinators' important ecosystem service, many countries support and encourage an increase in subsidies (Aizen & Harder, 2009) for specific landscape management in tandem with strong agri-environmental policy (Forney, 2016) or through investing in further research into other manageable pollinator species such as domesticated carpenter bees (*Xylocopa sonorin*), stingless (e.g. *Trigona carbonaria*) and various solitary bees (e.g. leafcutting bee *Megachile rotundata*) (Heard & Dollin, 2000; Pitts-Singer & Cane, 2011). Although these strategies focus on bees, there has also been recognition of the potential benefits of managing non-bees as crop pollinators such as *Eristalis tenax* (Nicholas et al., 2018).

A recent review of 39 studies conducted across several countries on different continents by Rader et al. (2016) suggests that non-bee insect pollinators play a significant role in global crop production. These non-bee pollinators can react differently to bees to different landscape features and patterns of land management and some may be less sensitive and responsive to particular landscape and farming management changes (Rader et al., 2016). Recent research in USA, Europe and South America clearly shows that native or semi-natural habitats within agricultural landscapes can increase wild bee populations (Jauker et al., 2009; Lentini et al., 2012; Ponisio et al., 2016; Venturini et al., 2017). However, the high fluctuation in food availability caused by the short flowering period of mass flowering monoculture crops is thought to make it difficult for large populations of wild pollinator insects to persist in these landscapes (Dicks et al., 2015). Native plantings at crop margins have the potential to provide food resources, improve their fitness and offer over-wintering refuges

to insects (Jonsson et al., 2008; Venturini et al., 2017) which then provide different ecosystem services such as pest control or pollination (Woltz et al., 2012).

Pest control and pollination service are both agro-ecosystem services that are vital to the productivity of agricultural systems (Sandhu et al., 2016). However, in New Zealand, studies quantifying the value of crop pollination services provided by wild species, how landscape features (e.g. existing hedgerows, fence lines), land use (e.g. organic, conventional) or interventions (such as native plantings) influence pollinator abundances, lifecycles and dispersal, are still sparse or non-existent. Similar, little research into weather variables which have been considered an important vector influencing the insects' behaviour (Arroyo et al., 1982a; Inouye & Pyke, 1988) has been conducted within agricultural landscapes.

1.2 New Zealand's agricultural pollination demands

In modern intensively farmed, monoculture landscapes (with high input of chemical fertiliser, pesticides, insecticides, ploughing, heavy machinery compacting soil etc.) the floral resources fluctuate tremendously during the season and are often dominated by a single mass flowering crop. In the Canterbury plains the majority of seeds grown are from the Brassicaceae (e.g., Pak choy *Brassica rapa* subsp*. chinensis*), legumes (e.g., white clover: *Trifolium repens*) allium (e.g., onion: *Allium cepa*), umbellifers (e.g., *Daucus carota*) and wind pollinated grains and grass seeds.

In New Zealand the manuka honey industry has encouraged a considerable increase in managed bee hives in the past decade (Ministry of Primary Industries, 2017)and these have been used partially for pollination work in orchards and crop field. However, reliance on one pollinating species may be causing shortfalls on potential crop yields as assemblages of pollinating species can support effective pollination of a wider range of crops and makes pollination services more resilient to changes (Rader et al., 2013). Wild insects, exotic and natives, can promote fruit set independently to honey bee visitation of crop flowers, and their presence alongside honey bees within crops could potentially double fruit set (Garibaldi et al., 2013), which has not been researched yet for New Zealand conditions.

Most research has found pollinator species diversity and abundance are negatively affected by distance to natural habitats (Bailey et al., 2014; Kremen et al., 2002; Ricketts et al., 2008; Zurbuchen et al., 2010). A New Zealand study by Stavert et al. (2018), however, found that numbers of exotic pollinators (such as *Eristalis tenax*) increase while native insects decrease with intensification of agriculture practice, (i.e. conversion of natural habitats to agriculture). On the other hand, Hartley (2018) showed in her study that the abundance of native bees, in the Taranaki

region, was positively associated with an increase in agricultural intensity. The ability to exploit introduced vegetation and find nest sites in mechanically worked soil might be the explanation for native bees, such as *Lasioglossum sordidum*, *L. cognatum* and *L paahaumaa*, to persist in New Zealand agricultural landscape (Hartley, 2018).

Based on the conclusion ofWinfree et al. (2011) he most prominent trait of an insect taxon associated with farm landscape intensification is the dietary specialisation, particularly for pollen specialists like bees, and specialised larval hosts of flies and butterflies (Winfree et al., 2011). Although the foraging preferences of New Zealand bees is well established (Donovan, 2007), there is less published information on non-bee pollinators. Moreover, it is not known whether establishing native plantings within highly intensified agricultural landscapes is sufficient to develop a diverse assemblage of pollinating species. Despite the possibility of benefits of native plantings as resource habitats for beneficial insects, these have to date been planted only sparsely in New Zealand farmland (Howlett, Davidson, Mathers, & Pyke, 2013).

1.3 New Zealand pollinators

New Zealand has a range of native and exotic pollinating insects. Bees and wasps (Hymenoptera), flies (Diptera), and butterflies and moths (Lepidoptera) are the major invertebrate groups which pollinate native plants (Donovan, 2007; Newstrom & Robertson, 2005) and exotic food crops. Of the native bees, *Leioproctus* species are the largest, with some species approaching honey bee size. *Lasioglossum* species are comparatively small, with a wide varied plant preferences (Donovan, 2007). *Lasioglossum* bees, particularly *L. sordidum* can be very abundant on crops including carrot (Howlett et al., 2015) and onion (Howlett, 2005). They are a ground-nesting bees and more numerous than those of all other native bees on the east coast of the South Island (Donovan, 2007). Indigenous bees in NZ are of low diversity, only 28 endemic bee species to date of which some are relatively primitive.

Since the 1830's eight exotic bee species have been deliberately introduced to New Zealand (Howlett & Donovan, 2010). Of these the honey bee, *Apis mellifera*, is considered to be the most useful pollinators for agriculture, visiting nearly all native and exotic plants found in New Zealand (Donovan, 2007; B G. Howlett & Donovan, 2010). Since New Zealand agriculture is largely derived from European plant species, it is not surprising that *Apis mellifera* is a successful and widely used pollinator for most of our insect pollinated crops (Free, 1993). However, other species may be equally or more efficient pollinators (Howlett et al., 2017; Howlett et al., 2011; Rader et al., 2009). *Bombus terrestris* as an example, are pervasive and are highly effective pollinators of some crops where honey bees are inefficient pollinators e.g. red clover (*Trifolium pratense*) and lucerne

(*Medicago sativa*) (Donovan, 1980). Another example are the Syrphidae, Colletidae, Tachinidae and Muscidae flies with some of their species valuable pollinators of exotic plant species such as seed crops (Howlett, 2012; Jauker et al., 2009; Rader et al., 2009) while a range of flies of the same families are considered critical in the pollination of some plants in New Zealand's alpine vegetation (Bischoff et al., 2013).

1.4 Questions

This study investigated the diversity and abundance of diurnal flower visitors and whether these are correlated specifically to the temporal flowering intensity of the blooming native plants. I am unaware of studies that have observed insect flower visitor on New Zealand native plantings across a full flowering cycle and asked if visiting species differ with changing crop phenology.

Global studies exist on the differential effects of variation in daily microclimate variables such as light, relative humidity, temperature and wind speed, on the foraging activity of the insect flower visitors (Herrera, 1995). However, research on weather variables and their effect on pollinators in New Zealand are sparse. Although Hartley (2018) describes in her study the appearance of native bees at certain weather conditions and documented a study for pollinator visiting crops such as onion, pak choi, carrots, white clover and radish crops in different regions of New Zealand, to my knowledge however the influence of weather variables on absence or presence of invertebrate on flowers in native plantings have not been documented. This present study aimed to fill some of these gaps in knowledge.

The specific questions addressed in this study are as follows:

1) What flower visitor diversity is recorded among native plantings in context of an arable landscape? Chapter 3
2) Are there known crop pollinators among the native plant flower visitors? Chapter 3
3) How does the composition of flower visitors vary over the summer flowering season? Chapter 4
4) Does each plant species attract a unique assemblage of flower visitors during its flowering season? Chapter 4
5) Which environmental variables affect the insect visitor composition on flowering plants? Chapter 4
6) What insect species are trapped at increasing increasing distances (0 to 250 m) from semi-natural habitat? Chapter 5

7) Do some insects carry the pollen of native trees from the plantings, and if so, what distance to the plantings are they captured with this pollen? Chapter 5

Chapter 2

Sites

2.1 Canterbury Plains: short natural history and agricultural usage today

The Canterbury Plains are around 180km long and 70km wide; they contain New Zealand's largest area of alluvial flat land (Meurk, 2008; Wilson, 2015). However, the plains seem flatter than they are, in fact, they are a sequence of gently sloping fans built up by the major rivers (Molloy, 1993).

Before Polynesian colonisation 1000 years ago, the region was dominated by podocarp forest which was changing after periodic fires. Tussock grassland dominated in higher altitude and in the lowland plains Kanuka (*Kunzea ericoides*) scrubland (Molloy & Ives, 1972), while a few remnants of podocarp forest persisted until European settlement. Mixed cropping farming system began at the end of 19th century (Haynes & Francis, 1990) where fertility-depleting cereals and food crops were typically grown for two to four years before the land was grazed with grass-clover pasture for yet another two to four years (Haynes & Francis, 1990). Food demand at the time was rapidly growing so Canterbury grew from 300 ha arable crops in 1858 to 160 000 ha by 1883 (Johnston, 1968) and then, 120 years later, to 212 000 ha (Statistics New Zealand 2008). This represents half of New Zealand's grain seed and fodder crop production and 75% of the small seed production (5537ha) (Statistic New Zealand, 2007).

From the 1980s onwards, the Canterbury dairy industry changed the land use more drastically. By 2010 dairy farming took up a tenfold of land compared to 30 years (Pangborn, 2012).

2.2 Climatic condition on the Plains

Canterbury's climate is characterised by settled weather phases with periods of strong drying northwest winds. Rainfall from west to east is a gradient from more than 1000mm on the western foothills to less than 500 mm on the coastline (NIWA, 2012). The median annual average temperatures are between 10^{o}C and 12^{o} C and the median annual sunshine hours around 2000hrs. These data are based on the 30 year period from 1981 to 2010 (NIWA, 2012).

Canterbury has access to plenty of water sources with rivers carrying mountain rainfall to the coast and aquifers which are tapped to irrigate farmland. Layers of porous gravels beneath the plains (up to 1600m in depth in some areas) allow the groundwater to disperse in sublayers (Wilson, 2015). However, due to the wind and porous ground, the plains have very dry growing conditions which make agricultural use difficult.

In the past decades dairy farmers, but also crop growers, have been intensifying their farmland by use of technological improvements, such as groundwater extraction for irrigation (Pangborn, 2012). The Canterbury Strategic Water Study report states that seventy percent of New Zealand's irrigated land is located in the Canterbury region which includes 58 percent of all water allocated for consumptive use in NZ (Morgan et al., 2002).

Such intensification is associated with greater inputs of inorganic fertilisers and other agrichemicals, which are in Canterbury successfully used for high-value specialist seed crops such as potatoes (93% of NZ seed potatoes crop) (Statistics New Zealand, 2008) brassica, carrot and onion seed production. Much of these crops are provided for northern hemisphere markets and support crop-based forages production for dairy industry (Moot et al., 2010).

The seed crops grown on the Plains are dependent on a sound pollination service to produce abundant and high-quality seed yields. The recent increase of cultivars in crop breeding programs might raise the need for cross-pollination further (Isaacs et al., 2017).

2.3 Sites

2.3.1 Farm 1

Farm 1 was located 23.2 km south of the Rakaia Township near Dorie (43º 33’ 56’’ S, 171º 41’ 35’’ E, 7 m above sea level) (Fig. 2-1, 2-2)

Figure 2-1 Farm 1 planting bordering the retention pond, looking towards W

Figure 2-2 Blue arrow points native plantings on Farm 1. Triangle shows water retention pond.

Imagery © 2018 Google Earth, ©2019 Maxar Technologies

2.3.2 Farm 2

Farm 2, 34.6 km southwest from Rakaia (43º 53’ 39’’ S, 171º 50’ 46’’ E, 21 m above sea level) (Fig.2-3, 2-4)

Figure 2-3 Native plants (5th year established), irrigated fields adjacent (Italian ryegrass)

Figure 2-4 Farm 2. Native plantings, 200m long, along field.
Imagery © 2018 Google Earth, ©2019 Maxar Technologies

2.3.3 Farm 3

Farm 3, 35.7 km northwest of Rakai Township near the Rakai Gorge (43º 53’ 32’’ S, 172º 06’ 55’’ E, 172 m over sea level) (Fig.2-5, 2-6)

Figure 2-5 Farm 3, mixture of diverse native species, with undergrowth sprayed off.

Figure 2-6 On Farm 3 the native plants were established as a blockplant of 50m x 60m size.
Imagery © 2018 Google Earth, ©2019 Maxar Technologies

All three conventionally managed farms were mixed-crop farms, with pasture used for grazing of stock. The three farms had native biodiverse plantings established in October 2013 as part of a project "Building better biodiversity on cropping farms" (Davidson, Howlett, & Walker, 2015). This project was funded by the Foundation for Arable Research and the Sustainable Farming Fund, and established by Stephen Brailsford and staff of Plant & Food Research Ltd. These native plant species were, whenever possible, accessed from locally sourced seeds. Plant species were chosen with the focus on providing resources and habitats for beneficial insects (i.e. ecosystem providers such as pollinators and pest predators) and being unlikely to harbour pest species (Davidson, Howlett, & Walker, 2015).

The plantings were between 300 m^2 and 640 m^2 and each consisted of 30–34 species, including 26 species that were shared across all sites (Appendix Table A. 1). The spacing between the seedlings within the native plantings was 1.5 m x 1.5 m throughout.

Eight of these shared species (Table A.1, green highlighted) which flowered during the summer season 2016/ 2017, were selected and tagged as study specimens (six specimens per species per farm).

Farm 1 included an apiary of 24 honey-bee colonies permanently placed 10m from the northwest edge of the native planting. This site was characterised by an irrigation pond. Along the pond's

southern embankments, “Trees for bees”(MAF SFF 10/009, 2012) plants were planted in 2012. These plant species were specifically chosen to provide honey bees with nectar and high-quality pollen throughout the early and late season and contained ‘trees for bees’ species such as; Mexican orange blossom (*Choicya ternata*), Californian lilac (*Ceanothus* sp.), Hebe species (i.e. *Veronica salicifolia*), rosemary (*Rosmarinus officinalis*), coast banksias (*Banksia integrifolia*), five-finger (*Pseudopanax arboreus*) and tree Lucerne (*Chamaecytisus palmensis*). The other side was planted with the native plants (no planting list was available) for the benefit of natural predators without becoming a reservoir for pest insects.

In 2017/18, the adjacent and nearby crops to the native plantings were seed crops of *Lolium perenne* (Farm 1,2), *Sinapis alba* (Farm 3), *Trifolium pratense* (Farm 2), *Avena sativa* (Farm 1), *Dactylis* sp. (Farm 2) or grazing paddock for sheep (Farm 3). Farm 1 and 2 used an irrigation system in their crops, while farm 3, close to the foothills, has a higher rainfall and therefore has not put in any irrigation systems.

2.4 Principal direct observation methods

Direct observation methods are a time-consuming labour-intensive method to spot flower visitors on open flowers, either on crops or native plants. However, it is a widely used to determine the flower visitor diversity and abundance (Bischoff, 2008; Chacoff & Aizen, 2006; Thompson, 2001). It was furthermore essential for our study to ensure that the insects were flower visitors on open receptive flowers, which could not be determined through an installed trapping system.

To ensure an even observation effort over a transect in every planting on each farm, my transect was divided into 6 subplots, the midpoint of each section was selected, and then the closest tree to the midpoint of the given species was chosen as marked specimen (Fig 2-7). Each marked specimen was visited and, if in bloom (>20% open flowers per bush), observed weekly until all flowers had completed their receptive period.

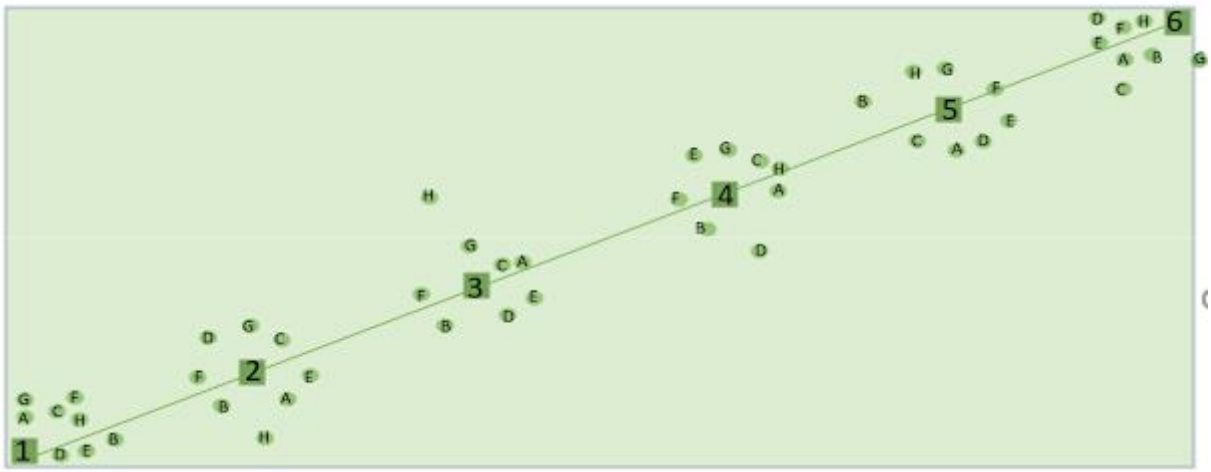


Figure 2-7 Design of the observational study on a transect in native plantings, showing the location of tagged plant specimens. A,B, to H are the eight chosen species. 1,2, to 6 are the # markers within the plantings.

Chapter 3

Insect visitors on native plants

3.1 Introduction

Little is known about the importance of perennially flowering woody vegetation in supporting pollinating insects in New Zealand (Howlett et al., 2013) but such vegetation is known to support arthropod biodiversity (Fukuda et al., 2011). Intensively farmed, largescale simplified landscapes are dominated by single mass-flowering crops resulting in large fluctuations in floral resources, and support less diverse insect communities than structurally complex natural habitats (Tscharntke et al., 2008). For wild pollinating species, Stavert et al. (2018) showed that here in New Zealand, agricultural expansion can increase the abundance of some exotic pollinators (i.e. *Eristalis tenax*) and compensate for the loss of native pollinators. However, a more biodiverse pollinator composition supports a wider range of crops and makes pollination services more resilient to environmental change (Rader et al., 2013). The Canterbury Plains has undergone significant agricultural intensification since European settlement and is currently dominated by livestock (particularly dairy) and arable farming (Dynes et al., 2010) notably oilseed rape, other brassicas, clover, onions, carrots, radishes as well as wind-pollinated grains and grasses. In such environments, the high variation in floral resource availability for pollinators is thought to make it difficult for large wild populations of pollinators to persist (Dicks et al., 2015). Furthermore, the widespread use of pesticides and herbicides associated with agricultural intensification and the paucity of semi-natural habitats can also impact ecosystem service providers like insect pollinators (Morandin & Kremen, 2013) and insect pest regulators (Davidson, Howlett, Butler, et al., 2015; Fontaine et al., 2006). With the worldwide more expensive upkeep of managed honey bee populations and the decline in feral honey bee colonies both thought to be due to agrochemicals, pathogens and climate change (Potts et al., 2010), the future regarding long-term crop-pollination service is uncertain. It is risky to rely on a single species to pollinate crops and produce food (Klein et al., 2007; Potts et al., 2010). Preserving landscapes that support wild pollinator populations can be regarded as an important and prudent insurance against potential failures in crops pollinated predominantly by honey bee (and bumble bee) populations (Garibaldi et al., 2013). Native or semi-native habitats within agricultural landscapes can increase wild bee populations (Jauker et al., 2009; Lentini et al., 2012; Ponisio et al., 2016; Venturini et al., 2017). This can support increased yields or yield consistency due to their complementarity with pollination services, for example through diversifying pollen transfer pathways (Garibaldi et al., 2013), differing activity patterns under variable weather conditions (Howlett et al., 2013) or seasonal activity (Howlett et al., 2016). Rader et al. (2016) analysed 39 studies conducted in

several countries across different continents, highlighting the significant role that non-bee insect pollinators play in global crop production.

A diversity of insect species (both bees and non-bees) visit the flowers of arable crops on the Canterbury Plains. These crops include pak choi *Brassica rapa* ssp. *chinensis* (Howlett, Walker, Newstrom-Lloyd, et al., 2009), onion *Allium cepa* (Howlett, 2005), carrot *Daucus carota* ssp. *sativus* (Howlett et al. 2015), and radish *Raphanus ativus* (Howlett, 2013). Native bees, bumblebees and several fly species have been verified as pollinators of pak choi (Howlett et al., 2011; Rader et al., 2009), onion (Howlett et al., 2017), carrot (Howlett, 2012) and other vegetable seed fields in Canterbury (B. Howlett unpublished data).

3.1.1 Objectives

This study was conducted to determine whether native plantings on arable farms support pollinator diversity.

Question:

1) What flower visitor diversity are recorded among native plantings in context of an arable landscape?
2) Are known crop pollinators among the native plant flower visitors?

3.2 Methods

3.2.1 Study system

Three farms within 50 km of Rakaia, Canterbury were assessed. All three farms had native biodiverse plantings established in October 2013. All plantings were located in the vicinity of crop fields in 2017/18. Eight of these shared species (Table A.1 green highlighted) were in bloom during the previous season and tagged as study specimens. Each marked specimen was visited and, if in bloom (>20% open flowers per bush), observed weekly. Please refer to Chapter 2 for more details on the study sites and plantings.

3.2.2 Monitoring insect activity on open flowers

Visual observations were used as neither the previously used methods (sticky-, window-, pan traps) (Howlett et al., 2013) nor the Malaise traps used in numerous studies worldwide (Campbell & Hanula, 2007; Hallmann CA. et al., 2017; Hutcheson & Jones, 1999) can be used to verify whether a captured insect species was a visitor of a specific plant. Moreover, the growth of the plantation to a

height of 4 m and characterised by dense undergrowth, also hindered the potential use of trapping methods.

Between September 2017 and February 2018, the insect observation surveys were conducted weekly on the eight chosen native plant species. The duration of each observation period was two-minute per plant with one minute each spent observing the north and sides. Therefore, at each plantation site, up to 90 minutes per day was spent observing target plants. This time varied depending how many trees were in open-flower stage. Timed counts of insects visiting a specific plant is an effective approach for standardised pollinator monitoring and is used commonly for data collection (Fijen & Kleijn, 2017; Howlett et al., 2018). However, Fijen and Kleijn (2017) found that even after observations on the focal plants for three consecutive days ,new pollinator species were still being recorded on the third day. The authors suggested that pollinator visitation rate during the plant's flowering time require observations across multiple days. Hence, weekly insect visitor observations were adopted in this study over a period of five months, to help ensure that recorded species richness is more likely to reflect true species occurrence for each plant species. Observations were only conducted on diurnal insects as these are currently the species that have been verified as crop pollinators (Howlett et al., 2018; Rader et al., 2009).

Each week, the order of farm visits was altered with varied observation times between 9:00 and 15:00. At the beginning and the end of each survey period the wind speed, ambient air temperature, relative humidity and light intensity was recorded. A TFA handheld windmeter was used to measure wind velocity (km h^{-1}) over a 30 second period with minimum and maximum speeds were recorded. Air temperature (°C) and relative humidity (%) were measured using a Thermo-Hydro recorder that was hung in full shade approximately 0.5 m above ground at the edge of the plantings.

Light intensity (irradiance) Watts (W)/m^2 was measured using a Daystar meter directed toward the north, the south and the sun.

Observations were made when the wind speed was no greater than 15km h^{-1}, the temperature was higher than 12ºC and no rainfall was occurring. Each landing of an insect on an open flower was recorded. Insect identifications was made by one or two researchers trained to recognise the known insect pollinators and common flower visitors.

Flower visiting insects were recorded on a spreadsheet to species level where possible, otherwise they were assigned to broader taxonomic groupings based on morphological characters. The survey spreadsheet was designed with a column of insect taxa believed most likely to be observed based on earlier preliminary observations (Howlett et al., 2018) Where possible, unknown flower visitors were caught and identified later with help of Sam Read (Plant and Food Research) and New Zealand native

bee specialist Barry Donovan (*Donovan* Scientific Insect Research). All the chosen samples of *Lasioglossum* sp. were identified as *L. sordidum,* but due to time constraint we weren't able to identify all the *Lasioglossum* specimens, therefore they were all named as *Lasioglossum sp.* However, the most abundant taxa were identified on the wing to the highest level of taxonomic resolution possible, largely to species (e.g. *Melangyna novaezealandiae)* or genus (e.g. *Leioproctus* spp*)* and less often to higher taxa (e.g. Family Tachinidae).

Insects smaller than < 3mm were not recorded. To date only a few studies have been conducted on small sized flower visitors of crops grown in New Zealand. These studies did not find evidence that thrips and other small insects contributed significantly to the pollination of pak choi (Walker et al., 2009) or onion (Walker et al., 2011) and their importance as pollinators remains to be assessed for other crops in New Zealand.

3.2.3 Data Analysis

As the focus of this study was to identify the flower-visiting species associated with the established native plants on arable farms and their occurrence across the plant species, formal statistical analyses were not considered necessary to achieve this aim.

3.3 Results

A total of 3088 flower visiting insects were counted in the biodiverse plantings across the three Canterbury Plains arable farms (Table 1). Bio-status could be assigned unambiguously to 94% of the insects of which 51% of those were natives. The eight most abundant flower visitors, that made up 82% of all visitors were, in decreasing abundance, *Apis mellifera* (adventive Apidae)*, Lasioglossum* species (indigenous Halictidae, mostly *L. sordidum*) *Melangyna novaezealandiae* (indigenous Syrphidae), *Calliphora stygia* (adventive Calliphoridae), *Dilophus nigrostigma* (endemic Bibionidae), *Calliphora vicina* (cosmopolitan Calliphoridae), *Leioproctus* species (indigenous Colletidae, a mix of *L. pango*, *L. boltoni*, and *L. fulvescens*) and *Eristalis tenax* (adventive Syrphidae) (Table 1).

Of the flower visitors, honey bees (*Apis mellifera*) were not always the most abundant nor the most generalist pollinator observed (Table 1). *Lasioglossum* bees were as abundant as honey bees overall and more abundant on some flowers. The hoverfly *Melangyna novaezealandiae* was the only insect observed visiting all eight tree species. Bees and wasps (Hymenoptera) in total comprised 45.8% of the total flower visitors with flies (Diptera) representing 52.4% of the visits (Table 1). The remainder were Lepidoptera (1.3%) and Coleoptera (0.6%). All surveys were diurnal and so did not account for potential

nocturnal insect activity. Unexpectedly the site with nearby honey bee hives did not contain the highest *A. mellifera* count. However, this site had a count of 25% more *Lasioglossum* spp. than *Apis mellifera*.

The most abundant flower visitors were seen at five or more of the eight tree species surveyed, with five insect taxa visiting 7–8 tree species (Table 1). All of the insects that visited the eight trees could be considered generalist flower visitors as the eight trees represent a range of plant families and floral structures. Even among the most generalist insect pollinators (generalists visit several plant species (Maldonado et al. (2013)), some tree species appeared to be favoured. While *Leioproctus* bees visited seven of the eight tree species, most of these visits were to *Carmichaelia australis* (45.1%) or *Veronica salicifolia* (41.2%). In contrast, while *Melangyna novaezealandiae* visited all plant species, most visits were to *Ozothamnus leptophyllus* (40.4%) or *Leptospermum scoparium* (27.2%).

Most tree species attracted a variety of insect flower visitors, from five (*Carmichaelia australis*) to 25 (*Veronica salicifolia*) insect taxa (Table 1). Diptera dominated the flower visitors for some tree species, especially *Leptospermum scoparium* (87.7% diptera), *Ozothamnus leptophyllus* (78.8% diptera), *Cordyline australis* (71.4% diptera), and *Kunzea serotina* (71.0% diptera). In contrast, bees and wasps (hymeoptera) dominated the visitors to *Carmichaelia australis* (94.9% hymenoptera), *Veronica salicifolia* (72.3% hymenoptera), and *Phormium tenax* (70.6% hymenoptera). *Discaria toumatou* visitors were 55.2% hymenoptera and 43.8% diptera.

Some tree species attracted many more flower visitors than others, with over half of insect flower visits recorded being on two plant species: *Veronica salicifolia* (37.1%) and *Cordyline australis* (24.0%). However, this measure combines floral attractiveness and the intensity of flowering in the surveyed season. The latter species is likely to vary considerably with year and plant age.

3.3.1 Species found on native plants

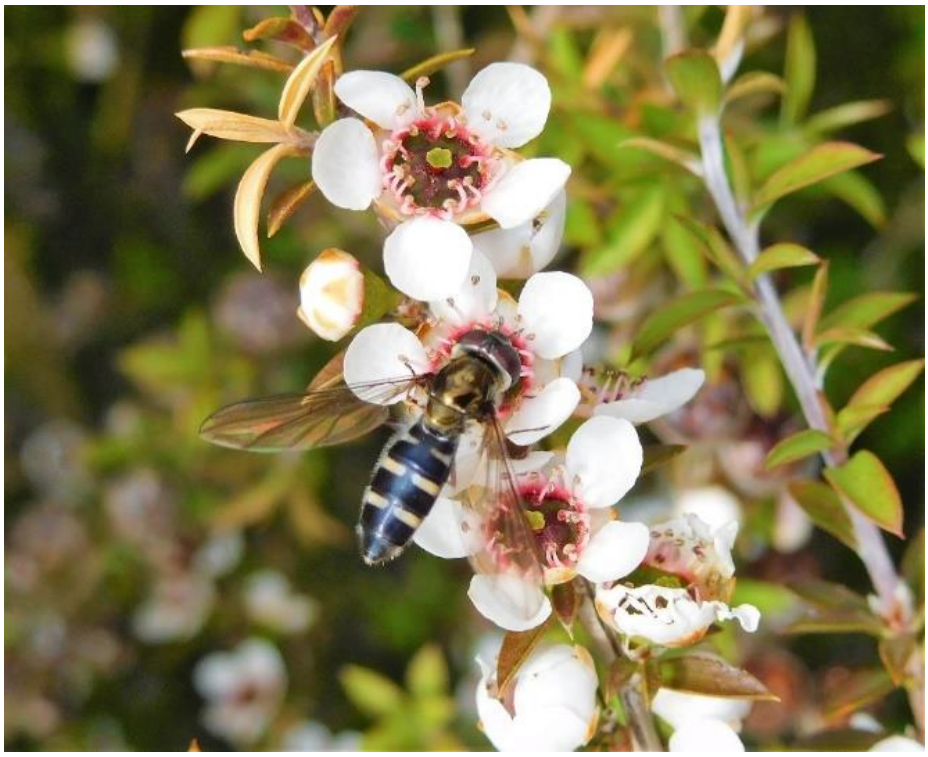


Figure 3-1 *Melangyna novaezealandiae* on *Kunzea sp.*

Figure 3-2 *Eristalis tenax* on *Veronica salicifolia*

Table 3-1 Flower visitors to eight species of planted indigenous trees at plantings on three Canterbury Plains arable farms. Displayed are the total visitors observed from weekly two minute counts to six individuals of each plant species at each site in fine weather between September 2017 and February 2018. The total number of insect visitors to each plant species is followed by the percentage of these visitors that were each insect taxon. Insect taxa are sorted by order of insects followed by the number of plant species visits. (Note that *Ozothamnus leptophyllus* includes the taxon *Ozothamnus vauvilliersii* at the inland site, currently regarded as part of *Ozothamnus leptophyllus* by NZ Plant Names.)

Plant species visited	**Flower visitor taxon**	***Carmichaelia australis***	***Cordyline australis***	***Discaria toumatou***	***Veronica salicifolia***	***Kunzea serotina***	***Leptospermum scoparium***	***Ozothamnus leptophyllus***	***Phormium tenax***	**Total**
	All taxa	164	905	96	872	111	298	505	137	3088
Hymenotpera										
8	*Lasioglossum* spp[a]	22.6%	6.6%	54.2%	31.4%	17.1%	0.7%	13.3%	15.3%	17.2%
8	*Leioproctus* spp[a]	55.5%	0.6%	1%	4.8%	9.9%	3.7%	1.2%	3.6%	5.6%
7	*Apis mellifera*[a] Linnaeus, 1758	15.9%	18.9%	-	33.5%	6.3%	11.4%	1.4%	40.1%	19.2%
4	*Bombus terrestris*[a] (Linnaeus, 1758)	-	0.8%	-	1.8%	-	-	1.2%	6.6%	1.2%
1	*Bombus hortorum*[a] (Linnaeus, 1761)	-	-	-	-	-	-	-	3.6%	0.2%
2	*Hylaeus* spp	0.6%	-	-	0.5%	-	-	-	-	0.2%
Diptera										
8	*Melangyna novaezealandiae*[a] (Macquart, 1855)	1.2%	7.8%	7.3%	1.4%	43.2%	37.9%	38.4%	6.6%	14.8%
7	*Calliphora vicina*[a]	-	10.8%	16.7%	2.3%	1.8%	19.1%	3.6%	4.4%	7%

Plant species visited	Flower visitor taxon	*Carmichaelia australis*	*Cordyline australis*	*Discaria toumatou*	*Veronica salicifolia*	*Kunzea serotina*	*Leptospermum scoparium*	*Ozothamnus leptophyllus*	*Phormium tenax*	Total
	Robineau- Desvoidy, 1830									
6	*Odontomyia* spp	0.6%	1%	-	2.9%	10.8%	1.3%	10.3%	-	3.3%
6	*Eristalis tenax*[a] Linnaeus, 1758	-	3.0%	1%	7.2%	1.8%	2%	2.4%	-	3.6%
6	*Dilophus nigrostigma*[a]	1.2%	19%	-	-	1.8%	7%	0.6%	13.1%	7.1%
6	*Lucilia* sericata[a] (Meigen, 1826)	-	2.4%	6.3%	1.4%	0.9%	3.4%	3%	-	2.1%
5	*Calliphora stygia*[a] (Fabricius, 1794)	-	21.5%	1%	-	-	5.7%	0.8%	0.7%	7.1%
4	*Melanostoma fasciatum*[a] (Macquart, 1850)	-	0.3%	-	3.7%	0.9%	-	1.8%	-	1.5%
4	*Oxysarcodexia varia* (Walker, 1836)	-	0.3%	-	1.6%	1.8%	-	3.8%	-	1.2%
4	*Calliphora quadrimaculata*[a] (Swederus, 1787)	-	0.2%	4.2%	1.3%	-	0.7%	-	-	0.6%
3	*Musca domestica,* Linnaeus, 1758	-	0.3%	-	0.1%	-	-	0.4%	-	0.2%
2	*Calliphora vomitoria* Linnaeus, 1758	-	0.3%	-	-	-	2.7%	-	-	0.4%

Plant species visited	Flower visitor taxon	*Carmichaelia australis*	*Cordyline australis*	*Discaria toumatou*	*Veronica salicifolia*	*Kunzea serotina*	*Leptospermum scoparium*	*Ozothamnus leptophyllus*	*Phormium tenax*	Total
2	*Pollenia* spp[a]	-	0.4%	-	-	-	-	0.7%	-	0.2%
1	*Pales usitata* (Hutton, 1901)	-	-	-	0.3%	-	-	-	-	0.1%
1	*Hydrotatea rostrate* Robineau-Desvoidy 1830	-	-	-	-	-	-	0.2%	-	<0.1%
1	*Hermetia illucens* (Linnaeus, 1758)	-	-	-	-	-	-	0.2%	-	<0.1%
1	*Protohystricia* spp	-	0.3%	-	-	-	-	0.2%	-	<0.1%
1	*Scaptia* spp	-	-	-	-	0.9%	-	0.2%	-	<0.1%
1	*Helophilus seelandicus* Gmelin, 1790	-	-	-	0.1%	-	-	-	-	<0.1%
3	Asilidae	0.6%	0.3%	-	-	-	-	0.2%	-	0.2%
Coleoptera										
5	*Coccinella undecimpunctata* Linnaeus, 1758	1.2%	-	-	0.2%	-	0.3%	1.8%	1.5%	0.5%
Lepidoptera										
3	*Vanessa itea*	-	0.3%	-	2.5%	-	-	0.2%	-	0.8%
1	*Pieris rapae* (Linnaeus 1758)	-	-	-	0.1%	-	-	-	-	<0.1%

Plant species visited	Flower visitor taxon	*Carmichaelia australis*	*Cordyline australis*	*Discaria toumatou*	*Veronica salicifolia*	*Kunzea serotina*	*Leptospermum scoparium*	*Ozothamnus leptophyllus*	*Phormium tenax*	Total
Other unidentified to species										
7	other Muscidae	-	3.6%	6.3%	1.1%	1.8%	1.3%	8.7%	2.2%	3.3%
5	other Calliphoridae	-	0.7%	1%	0.5%	-	-	2.6%	1.5%	0.8%
3	other Hymenoptera (wasps)	0.6%	-	-	0.2%	-	2.7%	-	-	0.4%
3	other Syrphidae	-	-	-	0.1%	0.9%	-	3%	-	0.6%
2	other Tachinidae	-	-	-	0.3%	-	-	0.2%	-	0.1%
1	other Lepidoptera	-	-	-	0.6%	-	-	-	-	0.2%
2	other Coleoptera	-	-	1%	2%	-	-	-	-	0.1%

[a] recognised crop pollinator

3.4 Discussion

The bio-diverse plantings at our study sites supported a diverse range of pollinating insects during the spring and summer months, which are critical flowering periods for seed crops that benefit from insect pollination (Howlett et al., 2016). Many of the insects recorded are known crop pollinators and it is plausible that these plantings boost on farm crop-pollinator populations early in the season. The ability of natural plantings to enhance the pollination of adjacent crops has been demonstrated elsewhere e.g., in California's Central Valley by Morandin and Kremen (2013). It is known that pollinators readily move to and from flowering crops fields (Mesa et al., 2013) and several species (e.g. flies and bees) move at least 400 m into the surrounding landscape (Rader et al., 2011). However, insect species would be expected to vary in their frequency and distance of dispersal from these native plantations, depending on their life cycles, behaviour and the attractiveness of nearby crops outside of the native plantings.

It is notable that several of the insect species recorded in our study were at least as abundant and generalised in their utilisation of flowering plant species as honey bees. Such insects have the potential to provide valuable pollination to crop fields, augmenting and complementing the pollination provided by managed honey bees. At this point in time, the management of wild pollinating species has been poorly explored in New Zealand, although one bee species *Leioproctus huakiwi* Donovan, 2007 (Donovan et al., 2010) has been successfully established at a site located on the New Zealand Institute for Plant & Food Research Limited, farm near Christchurch, Canterbury, New Zealand.

Considerable variation in the size and composition of the pollinator communities across the different tree species was documented. This study suggests that there is potential for enhancing crop pollination through increased pollinator diversity resulting from the presence of native biodiverse plantings on arable farms. In addition to pollinating insects, these plantings may also provide other ecosystem services to cropping systems such as supporting arthropods that predate on pest insects (Howlett et al., 2013). However, our understanding of the factors that could significantly influence species composition and distribution of arthropod assemblages on arable farms remains limited. The full economic and non-economic value of such plantings requires further study. This includes the diversity of native and exotic insect arthropods they support, aesthetic values, the value and consistency of ecosystem services they deliver to the farm and surrounding land uses. This knowledge is essential to provide grower or community incentive to establish similar plantings in the future.

Chapter 4

Seasonality of flowering native plants and visiting insect communities

4.1 Introduction

Observing plants and their flowering time has been of interest for people for centuries. Recording when the first flowers appear alongside when the first swallows arrive is a part of a long tradition; in the UK and USA it had it's peak in the 19th century (Tooke & Battey, 2010; Whitfield, 2001). In New Zealand Maori culture of Tikanga (experience and learning that has been handed down) is based on observing naturally occurring events and use them as markers to identify the end and beginning of a season. Observing migration patterns of birds, fish and phenology of flowering plants were, aside planetary movements (NIWA, 2006), an important knowledge to be handed down in generations before European arrived.

In temperate climates the flowering period is regulated by environmental cues primarily temperature and light intensity (Tooke & Battey, 2010). Correspondingly, the flight activity of insects visiting flowers is affected by environmental conditions also, such as ambient temperature, light intensity, wind speed, time of day and season (Kevan & Baker, 1983). Insects are less active when temperatures are exceptionally high or cool and windy (Arroyo et al., 1982b; Kevan & Baker, 1983). Likewise pollinator visitation rates to open flowers in temperate climates in early spring are believed to be lower than in later season, however these thoughts are often based on perceived conclusions of field observers rather than actual experimental or survey data (McCall & Primack, 1992). Undoubtedly, there is a degree of correlation between weather variables and seasonality regarding insect activity on flowering plants, however analysis to explain the variations of insect species associated to weather variables in crop pollinating environment is desirable to truly understand the complementarity (i.e. difference in activity both diurnally and seasonally) of wild and managed insects as pollinators of crop plants.

4.1.1 Blooming time and blossom structures of New Zealand native flora

Newstrom and Robertson (2005) searched Flora of New Zealand series for species with flowering time information. Of 729 native species with data 82% have their peak flowering time in December compared to 5% (39 species) in July. Most of the native plants in New Zealand have open-access or directed-access blossoms (Lloyd, 1985). Early observations on New Zealand native flora suggested

that insects were the most common floral visitors (Heine, 1938; Lloyd, 1985; Thomson, 1883). Flowers which group in compact inflorescences are exceptionally common, where else directed-access blossoms are less frequent. Spurred and closed-access blossoms are rare and uncommon in NZ (Lloyd, 1985). For open-access blossoms, the native flora in NZ relies on unspecialised native insect pollinators (Lloyd, 1985). On the contrary and plausibly, the few genera which possess a directed or closed-access blossom had typically low species diversity in flower visitors. Only one of 15 New Zealand genera retain a complex zygomorphic flower with a flag, *Carmichaelia* sp. (Fabaceae). Compared with most other parts of the world, New Zealand native plants rely on a higher proportion of unspecialised and imprecise insect pollinators (Lloyd, 1985; Newstrom & Robertson, 2005). In this country insect communities include exotic and indigenous pollinators of which the bee fauna are of particularly low diversity (Donovan, 1980) with just 28 described native species (Donovan, 2007; Donovan, 2016). The group of exotic pollinators however can be pervasive and effective pollinators (Donovan, 1980) in native and in the high proportion of introduced naturalised plants (52%) in New Zealand (Newstrom-Lloyd, 2013).

4.1.2 Crop Pollinators in New Zealand

While worldwide the enormous value of crop pollination by the managed *Apis mellifera* is undisputed (Klein et al., 2007; Kremen et al., 2002; Potts et al., 2010), other bee and fly species can be the prevailing pollinators in crops (Jauker et al., 2009; Rader et al., 2009). In particular, pollinators from different fly families (particularly Syrphidae, Calliphoridae) are often not included in estimates of agro-ecosystem pollination services (Rader et al., 2013) but are capable of contributing significantly to crop pollination (Howlett, 2012; Jauker & Wolters, 2008).

Up until now, studies on flower visitors on Canterbury's vegetable seed crops such as carrots (*Daucus carota* subsp. *Sativus),* pak choi *(Brassica rapa var. chinensi)*, and onion *(Allium cepa L.)* show that Calliphoridae (i.e. blowflies and cluster flies) and Sarcophagidae (flesh flies) are the most common flower visitors beside the managed *Apis mellifera* (Howlett et al., 2016; Howlett et al., 2011; Howlett, Walker, Newstrom-Lloyd, et al., 2009; Rader et al., 2012) (Table 4.1).

The most abundant key pollinators for these above-mentioned crops are the large hoverfly (*Melangyna novaezealandiae)*, March fly *(Dilophus nigrostigma)*, orange hoverfly (*Melanostoma fasciatum),* green soldier fly *(Odontomyia spp),* the native bee *Lasioglossum spp,* and as representatives of the Calliphoridae family the blue blowfly *(Calliphora vicina)* and *Pollenia spp.* (Foundation for Arable Research, 2012; Howlett, 2012; Howlett et al., 2016). The abundances of at least some of these species are known to very greatly and differently at a seasonal level (Donovan

2007; Howlett et al. 2016), however, to my knowledge, assessments on how the abundances of different species are influenced by different plant species flowering over time on farms in New Zealand has not been examined.

Table 4-1 Flower Visitors observed in different arable crops in New Zealand. With decreasing abundance from top down. References (Howlett, 2005, 2012; Howlett & Donovan, 2010; Howlett et al., 2017; Howlett et al., 2015; Howlett, Walker, McCallum, et al., 2009; Howlett, Walker, Newstrom-Lloyd, et al., 2009)

Insects	**Pak Choi, Turnip** *Brassica rapa* L.	**Onion** (*Allium cepa* L.)	**Carrot** *Daucus carota sativus*	**Radish** *Raphanus sativus* L	**White Clover**	**Red Clover**
Apis mellifera	x	x	x	X	X	X
Melangyna novaezealandiae		x	x	X		
Lasioglossum sp.	x	x	x			
Dilophus nigrostigma	x	x				
Eristalis tenax	x	x	x	X		
Melanostoma fasciatum		x				
Leioproctus spp	x	x				
Callliphora stygia	x	x	x			
Lucilia sericata		x	x			
Calliphora vicina		x	x			
Calliphora quadrimaculata			x			
Ichneumonidae wasps	x					
Odontomyia sp.	x	x	x			
Pollenia sp.		x				
Bombus terrestris	x	x	x	X	x	X

Insects	**Pak Choi, Turnip** *Brassica rapa* L.	**Onion** (*Allium cepa* L.)	**Carrot** *Daucus carota sativus*	**Radish** *Raphanus sativus* L	**White Clover**	**Red Clover**
Syrphidae	x	x	x	X	x	
Calliphoridae	x	x	x			
Tachinidae	x	x	x			
Muscidae	x	x	x			
Coccinellidae	x	x	x			
Lepidoptera	x	x	x			

4.1.3 Objectives

The aim of this Chapter was to assess the flower visitor communities and species abundances in relation to the flowering periods of seven native plants during a flowering summer season. The research additionally collected on-site weather data to determine the strength of each weather variable on the insect visitation rate within the native plantings. Correlations between these environmental conditions and each individual insect species were examined.

The questions addresses were:

1) How does the composition of flower visitors vary over the summer flowering season?
2) Does each plant species attract a unique assemblage of flower visitors during its flowering season?
3) Which of the environmental variables affect the pollinator composition on flowering plants?

4.1.4 Study sites

The data collection was conducted on three arable farms within 50 km of Rakaia, Canterbury. Native biodiverse plantings were established in October 2013 on all three farms. Seven plant species in bloom were tagged as study specimens. Each marked specimen was visited and, if in bloom (>20% open flowers per plant), observed weekly. Weather data was collected on each of the visits.

Please refer to Chapter 2 for more details on local arable history, study sites and plantings.

4.2 Data Analysis

Generalised linear models (GLM) in R (R Core Team, 2018) were used to assess effects of the environmental variables on the abundance of each of the eight most common insect species. Poisson error distribution was used in the model. Insect abundance was modelled as a function of property, date, the square of date (to fit a curve with one inflection point), plant species, the weather variables (temperature, humidity, maximum wind and light) and all two-way interactions among the weather variables. *Post-hoc* pairwise comparison between plant species were calculated using the glht function from the multcomp package (Hothorn et al., 2008) with the Tukey method. To assess the goodness of fit of the model to the data Schielzeth and Nakagawa's R^2 (Nakagawa & Schielzeth, 2013) was calculated using rsquared function of the piecewiseSEM package (Lefcheck, 2015).

In order to describe how the overall community composition of flower visitors varied among surveys of plants of different species, farms, and dates, an indirect gradient analysis, using non-metric multi-dimensional scaling (NMDS)(Borcard, 2018) was used. This analysis exploits rank orders and is therefore a flexible technique which accommodates the variety of different kind of data my study has collected. This collapsing of information from multiple dimensions (e.g. multiple communities, threes sites and six weather variables) into just a few, allowed to visualise and interpret this data set.

The NMDS was performed using the metaMDS function in the R package vegan (Jari et al., 2018) using the Gow dissimilarity index with Wisconsin scaling (this was the best index for aligning with the environmental data according to the rankindex function of vegan). The noshare setting in metaMDS was set to 0.1 to exclude outliers. With a 3-axis NMDS the stress value, a measure of goodness of fit, was 0.18, which is too high. To achieve an acceptable stress value, four dimensions were required to achieve an acceptable stress value (0.152). The ordination was set to run with 999 permutations, using the observed data, although the model converged before these many permutations.

Environmental vectors were fitted using vegan's envfit function to visualise the relative importance and direction of the effects of the continuous environmental variables (weather data and date).

Using Adonis interactions function allows an indication of whether any of the environmental variables are associated with differences insect species relative abundances.
Permutational Multivariate Analysis of Variance using adonis, from the vegan package, was used to test the statistical significance of the effects of environmental variables on the differences in flower visitor composition among plant surveys. Vegan's adonis function is based on Anderson (2001) and performs a sequential test of terms. I analysed the effects of the following variables on the insect composition: date, plant species, temperature, humidity, maximum wind, light, and property, in that order, including all two-way interactions. The Gow dissimilarity index was used once more.

To further tease out potential effects of plant species on flower visitor composition, the following *a priori* contrasts were applied in the adonis model: *Carmichaelia australis* versus *Phormium tenax*, *C. australis* and *P. tenax* versus the other species, *Ozothamnus* sp. versus the remaining other species, *Veronica salicifolia* and *Cordyline autralis* versus *Kunzea serotina* and *Leptospermum scoparium*, *K. serotina* versus *L. scoparium*, and *V. salicifolia* versus *Cordyline australis*. These contrasts were selected based on degree of differences in the morphology of the flowers. Species with morphologically more different flowers were expected to be more likely to differ in the composition of their flower visitors.

4.3 Results

A total of 3033 flower visiting insects were counted in the native plantings across the three arable farms in Canterbury (Table 1, Chapter 3).

4.3.1 Flowering phases of seven native plant species

The summer 2017/18 was the hottest summer in New Zealand since 1934 with (summer average temperatures of 18.8^{o}C , 2.1^{o}C above average of the past 30 years (NIWA, 2017). With an early spring occurring six of seven plant species were in bloom simultaneously, at the end of November/ beginning of December (Fig. 4.1). *Veronica salicifolia* was the last species to start flowering, beginning in early December, and it was in bloom for almost 2 months (over three locations) into the end of January (Fig 4.1). At the opposite extreme was *Cordyline australis*, which was the first to start and finish flowering (Fig 4.1).

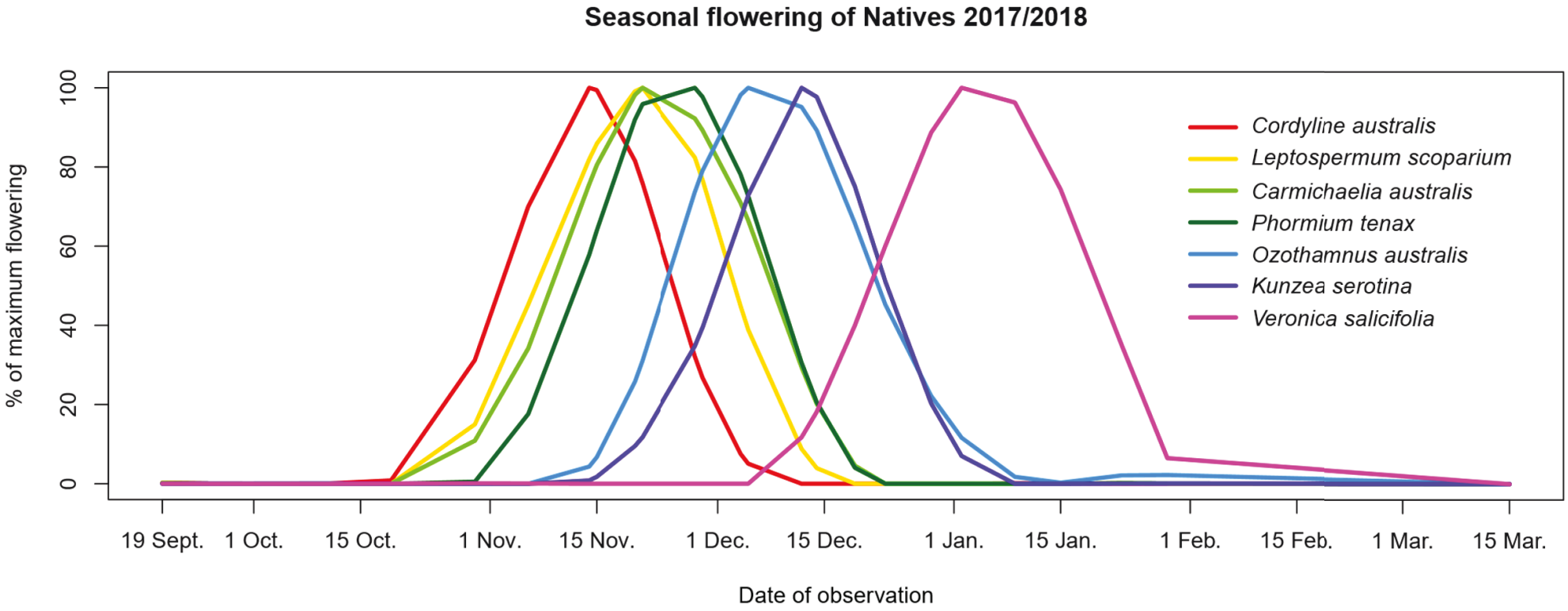


Figure 4-1 Flowering sequences of seven plant species in the native plantings established on arable farms on the Canterbury Plains. For each species the curve depicts peak flowering (100%). Five of seven species in the transect displayed open or semi open flowers.

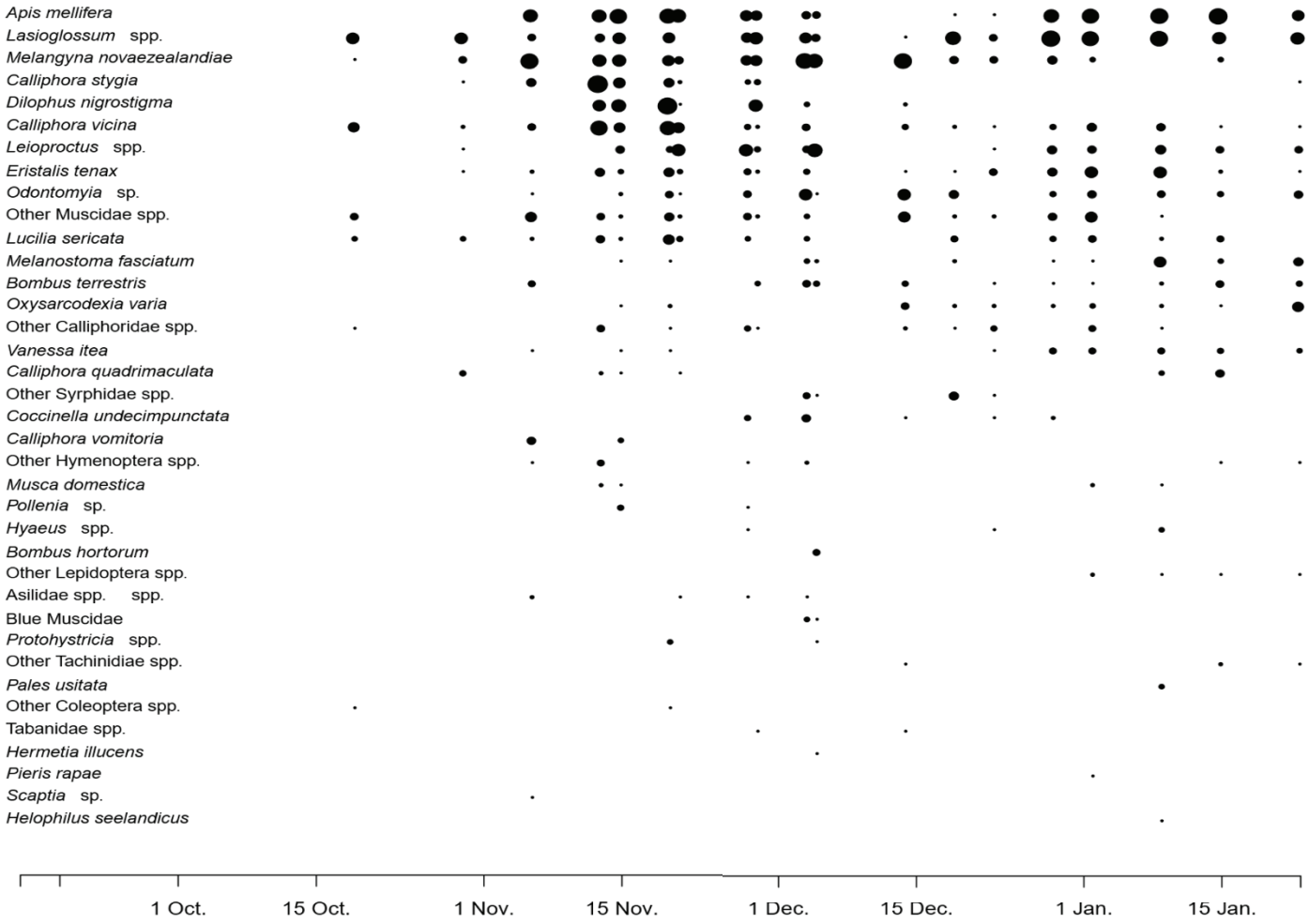


Figure 4-2 Insect visitation on seven plant species during a flowering season 2017/18. Circle size is linearly proportional to the total number of each species counted on each date, order from most common to least common. Two dots close to each other were closest observation dates possible in different fields.

4.3.2 Flower visitor abundancy

Figure 4.2 shows the variation in abundance of each insect species over the study, as assessed by flower visitor counts. Some species showed stronger seasonal variation in numbers than others.

It is apparent from Fig 2 that from the beginning to the end of the native plants' flowering phase (mid-October to end of January), there was sustained flower visitation from a diversity of insects (37 taxa). The majority of the eight most abundant flower visitors (representing 82% of all recorded insects, Chapter 3), were active throughout the whole season. The exception to this is very early in the season, when only *Lasioglossum* sp. and *Calliphora vicina*, and a couple of other members of the Calliphoridae and Muscidae families, were present. *Lasioglossum* sp. was recorded consistently during the whole flowering season. The shortest appearances were *Dilophus nigrostigma* and *Calliphora stygia,* which were each present for period of only two weeks, from mid to end of November.

The effect of date on the abundance of the eight most abundant insect species are described in more detail below in the sections on each species.

4.3.3 Insect abundance on different plant species

The eight most abundant insects visiting flowers over the course of this study were, in order, *Apis mellifera*, *Lasioglossum* sp., *Melangyna novaezealandiae*, *Calliphora stygia*, *Dilophus nigrostigma*, *Calliphora vicina, Leioproctus* spp. and *Eristalis tenax* (Table 1) (Chapter 3). Each of these species responded to date, plant species, and weather in different ways.

The number of *Lasioglossum* sp. counted in each 2minute survey was significantly affected by property, date, plant species, temperature, humidity and the interactions between temperature and humidity, temperature and wind, and humidity and light (Table 4-2). The GLM explained a majority of the variation in *Lasioglossum* sp. counts, having an R^2 of 0.80. *Lasioglossum* counts were higher with lower temperature and less humidity (Table 4-2 b)). *Lasioglossum* abundance was highest early and late in the season (Fig 4.2) with a slight decline at the end of the season (Table 4-2).

Lasioglossum sp. abundance differed significantly among plant species (Table 4-3, Fig. 4-3). It was seen more often on *Cordyline australis* and *Carmichelia australis* than *Kunzea serotina*, *Leptospermum scoparium*, *Phormium tenax*, and *Ozothamnus leptophyllus*. It also was observered more on *Veronica salicifolia* than *L. scoparium* and *O. leptophyllus*.

Table 4-2 **(a)** ANOVA tables of the GLM of *Lasioglossum* sp .abundance by property, date, plant species, temperature, humidity, maximum wind speed, light towards sun, and the interactions between the weather variables. I((Date)^2) allows the effect of date on abundance to curve up or down over the season. Bold figures indicate p<0.05. **(b)** The estimates of the poisson GLM model, predicting the log of *Lasioglossum* sp. abundance.

a)

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL	NA	NA	251	1043.274	NA
Property	2	22.359	249	1020.915	**0.000**
Date	1	133.344	248	887.571	**0.000**
I((Date)^2)	1	30.592	247	856.979	**0.000**
plant_sciname	6	133.032	241	723.948	**0.000**
Temperature	1	11.051	240	712.897	**0.001**
Humidity	1	6.727	239	706.170	**0.009**
Wind.max	1	0.405	238	705.765	0.524
Light.sun	1	0.026	237	705.739	0.872
Temperature:Humidity	1	24.445	236	681.294	**0.000**
Temperature:Wind.max	1	4.799	235	676.495	**0.028**
Temperature:Light.sun	1	2.224	234	674.271	0.136
Humidity:Wind.max	1	1.688	233	672.582	0.194
Humidity:Light.sun	1	19.830	232	652.752	**0.000**
Wind.max:Light.sun	1	0.059	231	652.693	0.808

b)

	Estimate
intercept	-80.959
Farm 3	0.160
Farm2	0.557
Date	0.583
I((Date)^2)	-0.001
plant_scinameCordyline australis	0.243
plant_scinameKunzea	-1.204
plant_scinameLeptospermum scoparium	-3.362
plant_scinameOzothamnus leptophyllus	-0.909
plant_scinamePhormium tenax	-1.014
plant_scinameVeronica salicifolia	-0.276
Temperature	-1.402
Humidity	-0.385
Wind.max	-0.665
Light.sun	0.010
Temperature:Humidity	0.022
Temperature:Wind.max	0.018
Temperature:Light.sun	0.000
Humidity:Wind.max	0.004
Humidity:Light.sun	0.000
Wind.max:Light.sun	0.000

Table 4-3 Post hoc pairwise comparison of *Lasioglossum* sp. abundance among plant species were calculated using the glht function with the Tukey method.

	Estimate	Std. Error	z value	Pr(>|z|)
Cordyline australis - Carmichaelia australis	0.243	0.236	1.029	0.935
Kunzea - Carmichaelia australis	-1.204	0.323	-3.725	**0.003**
Leptospermum scoparium - Carmichaelia australis	-3.362	0.740	-4.544	**< 0.001**
Ozothamnus leptophyllus - Carmichaelia australis	-0.909	0.314	-2.895	**0.048**
Phormium tenax - Carmichaelia australis	-1.014	0.280	-3.624	**0.004**
Veronica salicifolia - Carmichaelia australis	-0.277	0.340	-0.814	0.979
Kunzea - Cordyline australis	-1.447	0.341	-4.247	**< 0.001**
Leptospermum scoparium - Cordyline australis	-3.605	0.728	-4.951	**< 0.001**
Ozothamnus leptophyllus - Cordyline australis	-1.152	0.345	-3.340	**0.012**
Phormium tenax - Cordyline australis	-1.256	0.274	-4.594	**< 0.001**
Veronica salicifolia - Cordyline australis	-0.519	0.371	-1.400	0.769
Leptospermum scoparium - Kunzea	-2.158	0.776	-2.782	0.065
Ozothamnus leptophyllus - Kunzea	0.295	0.290	1.016	0.939
Phormium tenax - Kunzea	0.191	0.342	0.557	0.997
Veronica salicifolia - Kunzea	0.928	0.301	3.087	**0.027**
Ozothamnus leptophyllus - Leptospermum scoparium	2.453	0.776	3.161	**0.021**
Phormium tenax - Leptospermum scoparium	2.349	0.752	3.125	**0.024**
Veronica salicifolia - Leptospermum scoparium	3.086	0.788	3.915	**0.001**
Phormium tenax - Ozothamnus leptophyllus	-0.104	0.338	-0.308	1.000
Veronica salicifolia - Ozothamnus leptophyllus	0.633	0.158	3.996	< **0.001**
Veronica salicifolia - Phormium tenax	0.737	0.361	2.042	0.344

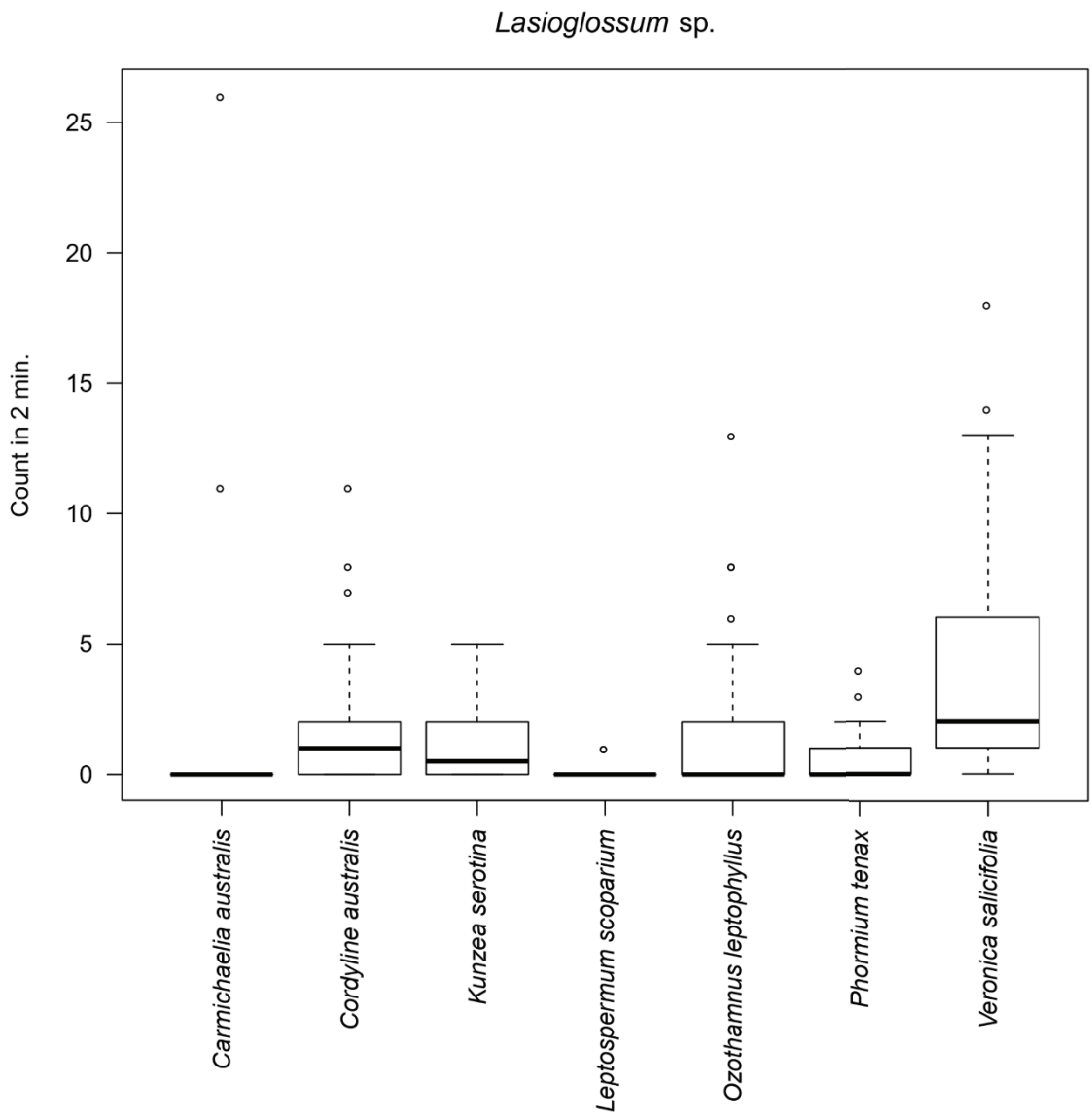


Figure 4-3 *Lasioglossum* sp. was a generalist flower visitor, visiting all seven native plant species, although some species were visited more than others.

For ***Apis mellifera***, date, plant species, humidity, wind and light significantly affected its abundance. All interactions but one (humidity/wind) were also significant (Table 4-4).

The GLM explained a majority of the variation in *Apis mellifera* counts, having an R^2 of 0.88. *Apis mellifera* were missing in the very early surveys but then persisted throughout the season (Fig. 4-2). *Apis mellifera* counts were higher with higher humidity and light but less wind (Table 4-4b).

Even though *Apis mellifera* is a generalist in pollination, it visited *Veronica salicifolia* more than *Cordyline australis, Phormium tenax, Leptospermum scoparium, Ozothamnus leptophyllus and Carmichaelia australis. Cordyline australis* was observed significantly more than *Leptospermum scoparium*, *Carmichaelia australis*, *Ozothamnus leptophyllus*, and *Phormium tenax* (Table 4-5, Fig. 4-4).

Table 4-4 **(a)** ANOVA tables of the GLM of *Apis mellifera* abundance by property, date, plant species, temperature, humidity, maximum wind speed, light towards sun, and the interactions between the weather variables. I((Date)^2) allows the effect of date on abundance to curve up or down over the season. Bold figures indicate p<0.05. **(b)** The estimates of the poisson GLM model, predicting the log of *Apis mellifera* abundance.

a)

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL	NA	NA	251	1094.461	NA
Property	2	4.684	249	1089.777	0.096
Date	1	14.016	248	1075.761	**0.000**
I((Date)^2)	1	73.966	247	1001.794	**0.000**
plant_sciname	6	297.678	241	704.117	**0.000**
Temperature	1	0.000	240	704.117	0.997
Humidity	1	4.394	239	699.723	**0.036**
Wind.max	1	4.586	238	695.137	**0.032**
Light.sun	1	17.492	237	677.645	**0.000**
Temperature:Humidity	1	48.199	236	629.447	**0.000**
Temperature:Wind.max	1	8.802	235	620.645	**0.003**
Temperature:Light.sun	1	9.330	234	611.315	**0.002**
Humidity:Wind.max	1	2.177	233	609.139	0.140
Humidity:Light.sun	1	28.895	232	580.244	**0.000**
Wind.max:Light.sun	1	6.338	231	573.906	**0.012**

b)

	Estimate
Intercept	52.811
Farm 3	-0.178
Farm 2	0.005
Date	-0.405
I((Date)^2)	0.001
plant_scinameCordyline australis	1.557
plant_scinameKunzea	-0.395
plant_scinameLeptospermum scoparium	-0.205
plant_scinameOzothamnus leptophyllus	-1.315
plant_scinamePhormium tenax	0.435
plant_scinameVeronic salicifolia	1.967
Temperature	0.383
Humidity	0.393
Wind.max	-1.111
Light.sun	0.017
Temperature:Humidity	-0.009
Temperature:Wind.max	0.021
Temperature:Light.sun	0.000
Humidity:Wind.max	0.008
Humidity:Light.sun	0.000
Wind.max:Light.sun	0.000

Table 4-5 Post hoc pairwise comparison of *Apis mellifera* abundance among plant species were calculated using the glht function with the Tukey method.

	Estimate	Std. Error	z value	Pr(>|z|)
Cordyline australis - Carmichaelia australis	1.557	0.239	6.519	**< 0.001**
Kunzea - Carmichaelia australis	-0.395	0.454	-0.870	0.973
Leptospermum scoparium - Carmichaelia australis	-0.205	0.265	-0.774	0.985
Ozothamnus leptophyllus - Carmichaelia australis	-1.315	0.482	-2.729	0.079
Phormium tenax - Carmichaelia australis	0.435	0.240	1.813	0.504
Veronica salicifolia - Carmichaelia australis	1.967	0.469	4.197	**< 0.001**
Kunzea - Cordyline australis	-1.952	0.443	-4.411	**< 0.001**
Leptospermum scoparium - Cordyline australis	-1.762	0.209	-8.414	**< 0.001**
Ozothamnus leptophyllus - Cordyline australis	-2.872	0.482	-5.961	**< 0.001**
Phormium tenax - Cordyline australis	-1.122	0.193	-5.826	**< 0.001**
Veronica salicifolia - Cordyline australis	0.410	0.487	0.842	0.977
Leptospermum scoparium - Kunzea	0.190	0.454	0.419	0.999
Ozothamnus leptophyllus - Kunzea	-0.920	0.546	-1.684	0.593
Phormium tenax - Kunzea	0.830	0.428	1.940	0.419
Veronica salicifolia - Kunzea	2.362	0.483	4.891	**< 0.001**
Ozothamnus leptophyllus - Leptospermum scoparium	-1.110	0.485	-2.287	0.223
Phormium tenax - Leptospermum scoparium	0.640	0.227	2.821	0.061
Veronica salicifolia - Leptospermum scoparium	2.172	0.478	4.546	**< 0.001**
Phormium tenax - Ozothamnus leptophyllus	1.750	0.454	3.853	**0.002**
Veronica salicifolia - Ozothamnus leptophyllus	3.282	0.446	7.352	**< 0.001**
Veronica salicifolia - Phormium tenax	1.532	0.441	3.478	**0.008**

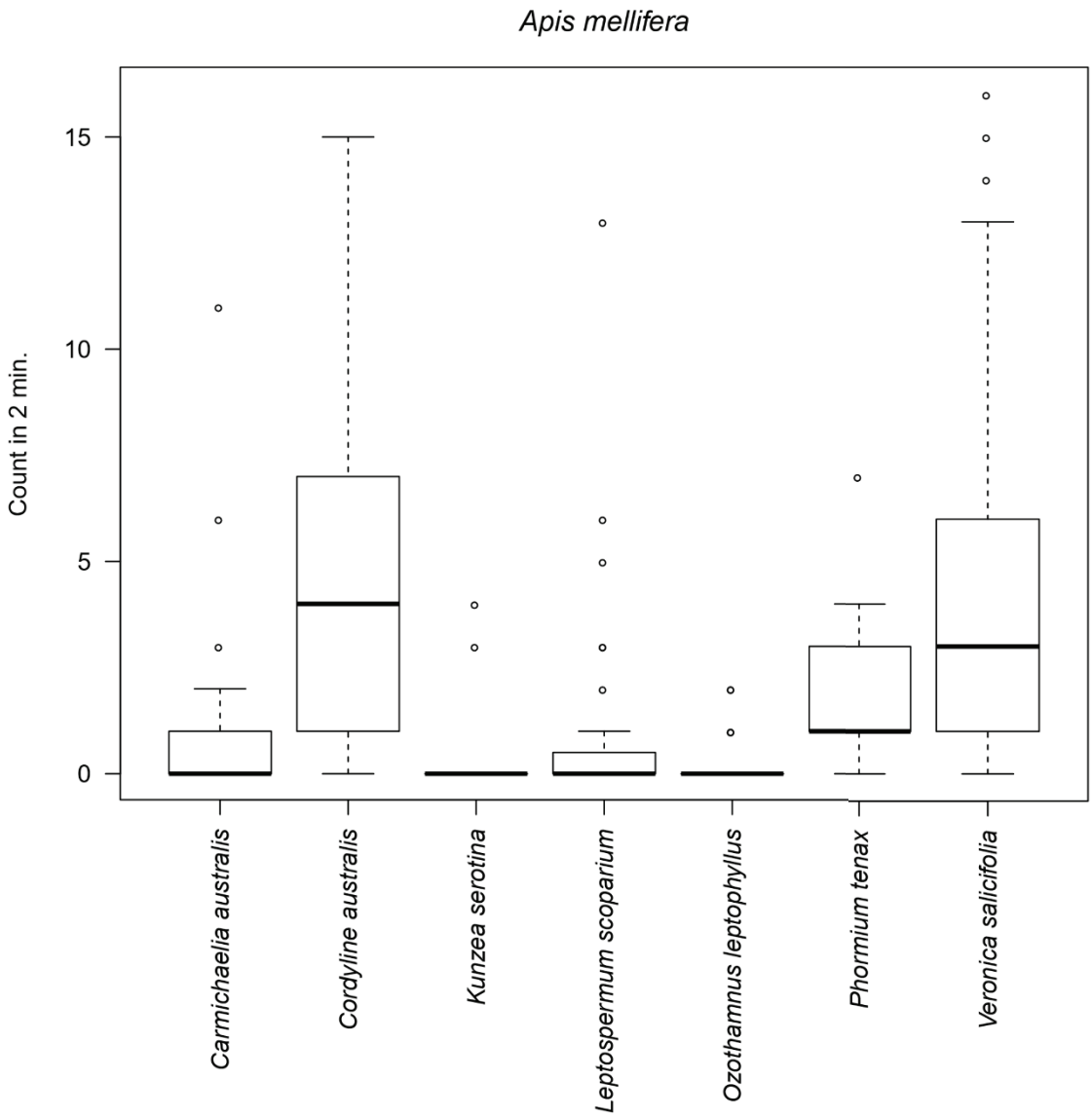


Figure 4-4 *Apis mellifera* was a generalist flower visitor, visiting all seven native plant species, although some species were visited more than others.

For ***Melangyna novaezealandiae***, all variables were significant except the interactions between temp and wind, temp and light, humidity and wind and also light (Table 4-6). The GLM explained a majority of the variation in *M. novaezealandiae* counts, having an R2 of 0.96.

Melangyna novaezealandiae counts were higher with higher temperature and wind, and with lower light level and humidity (Table 4-6 b).

Melangyna novaezealandiae was not observed at the very beginning of the flowering time of the natives. Their abundance peaked end of November and during December, with dwindling numbers in January (Fig. 4-2). *M. novaezealandiae* has been seen on all plant (Table 4-7, Fig. 4-6) species but the largest numbers were on *Ozothamnus leptophyllus.* It was observed significantly more often on *O. leptophyllus* than on *Carmichaelia australis*, *Cordyline australis*, *Phormium tenax*, and *Leptospermum scoparium* but not more than *Kunzea serotina* and *Veronica salicifolia.*

Table 4-6 **(a)** ANOVA tables of the GLM of *Melangyna novaezealandiae* abundance by property, date, plant species, temperature, humidity, maximum wind speed, light towards sun, and the interactions between the weather variables. I((Date)^2) allows the effect of date on abundance to curve up or down over the season. Bold figures indicate p<0.05 **(b)** The estimates of the poisson GLM model, predicting the log of *Melangyna novaezealandiae* abundance.

a)

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL	NA	NA	251	1181.826	NA
Property	2	68.577	249	1113.249	**0.000**
Date	1	116.522	248	996.727	**0.000**
I((Date)^2)	1	38.135	247	958.592	**0.000**
plant_sciname	6	421.128	241	537.464	**0.000**
Temperature	1	10.555	240	526.909	**0.001**
Humidity	1	46.521	239	480.388	**0.000**
Wind.max	1	11.395	238	468.993	**0.001**
Light.sun	1	11.196	237	457.797	**0.001**
Temperature:Humidity	1	20.557	236	437.240	**0.000**
Temperature:Wind.max	1	0.007	235	437.233	0.935
Temperature:Light.sun	1	1.994	234	435.240	0.158
Humidity:Wind.max	1	0.441	233	434.798	0.507
Humidity:Light.sun	1	1.024	232	433.775	0.312
Wind.max:Light.sun	1	12.018	231	421.757	**0.001**

b)

	Estimate
Fram 1	126.183
Farm 3	1.298
Farm 2	0.065
Date	0.802
I((Date)^2)	-0.001
plant_scinameCordyline australis	2.330
plant_scinameHebe salicifolia	3.277
plant_scinameKunzea	3.949
plant_scinameLeptospermum scoparium	3.128
plant_scinameOzothamnus leptophyllus	4.174
plant_scinamePhormium tenax	0.980
Temperature	0.292
Humidity	-0.013
Wind.max	1.079
Light.sun	-0.017
Temperature:Humidity	-0.010
Temperature:Wind.max	-0.010
Temperature:Light.sun	0.000
Humidity:Wind.max	-0.009
Humidity:Light.sun	0.000
Wind.max:Light.sun	0.000

Table 4-7 Post hoc pairwise comparison of *Melangyna novaezealandiae* abundance among plant species were calculated using the glht function with the Tukey method.

	Estimate	Std. Error	z value	Pr(>|z|)
Cordyline australis - Carmichaelia australis	2.330	0.730	3.194	**0.019**
Kunzea - Carmichaelia australis	3.949	0.728	5.420	**< 0.001**
Leptospermum scoparium - Carmichaelia australis	3.128	0.732	4.276	**< 0.001**
Ozothamnus leptophyllus - Carmichaelia australis	4.174	0.718	5.811	**< 0.001**
Phormium tenax - Carmichaelia australis	0.980	0.784	1.250	0.847
Veronica salicifolia - Carmichaelia australis	3.277	0.835	3.926	**0.001**
Kunzea - Cordyline australis	1.619	0.261	6.209	**< 0.001**
Leptospermum scoparium - Cordyline australis	0.798	0.198	4.029	**< 0.001**
Ozothamnus leptophyllus - Cordyline australis	1.844	0.226	8.150	**< 0.001**
Phormium tenax - Cordyline australis	-1.351	0.369	-3.657	**0.004**
Veronica salicifolia - Cordyline australis	0.947	0.487	1.944	0.400
Leptospermum scoparium - Kunzea	-0.820	0.274	-2.990	**0.035**
Ozothamnus leptophyllus - Kunzea	0.225	0.177	1.273	0.836
Phormium tenax - Kunzea	-2.969	0.377	-7.883	< **0.001**
Veronica salicifolia - Kunzea	-0.672	0.441	-1.524	0.686
Ozothamnus leptophyllus - Leptospermum scoparium	1.046	0.248	4.218	**< 0.001**
Phormium tenax - Leptospermum scoparium	-2.149	0.379	-5.671	**< 0.001**
Veronica salicifolia - Leptospermum scoparium	0.149	0.494	0.301	1.000
Phormium tenax - Ozothamnus leptophyllus	-3.194	0.353	-9.044	**< 0.001**
Veronica salicifolia - Ozothamnus leptophyllus	-0.897	0.427	-2.103	0.304
Veronica salicifolia - Phormium tenax	2.297	0.554	4.145	**< 0.001**

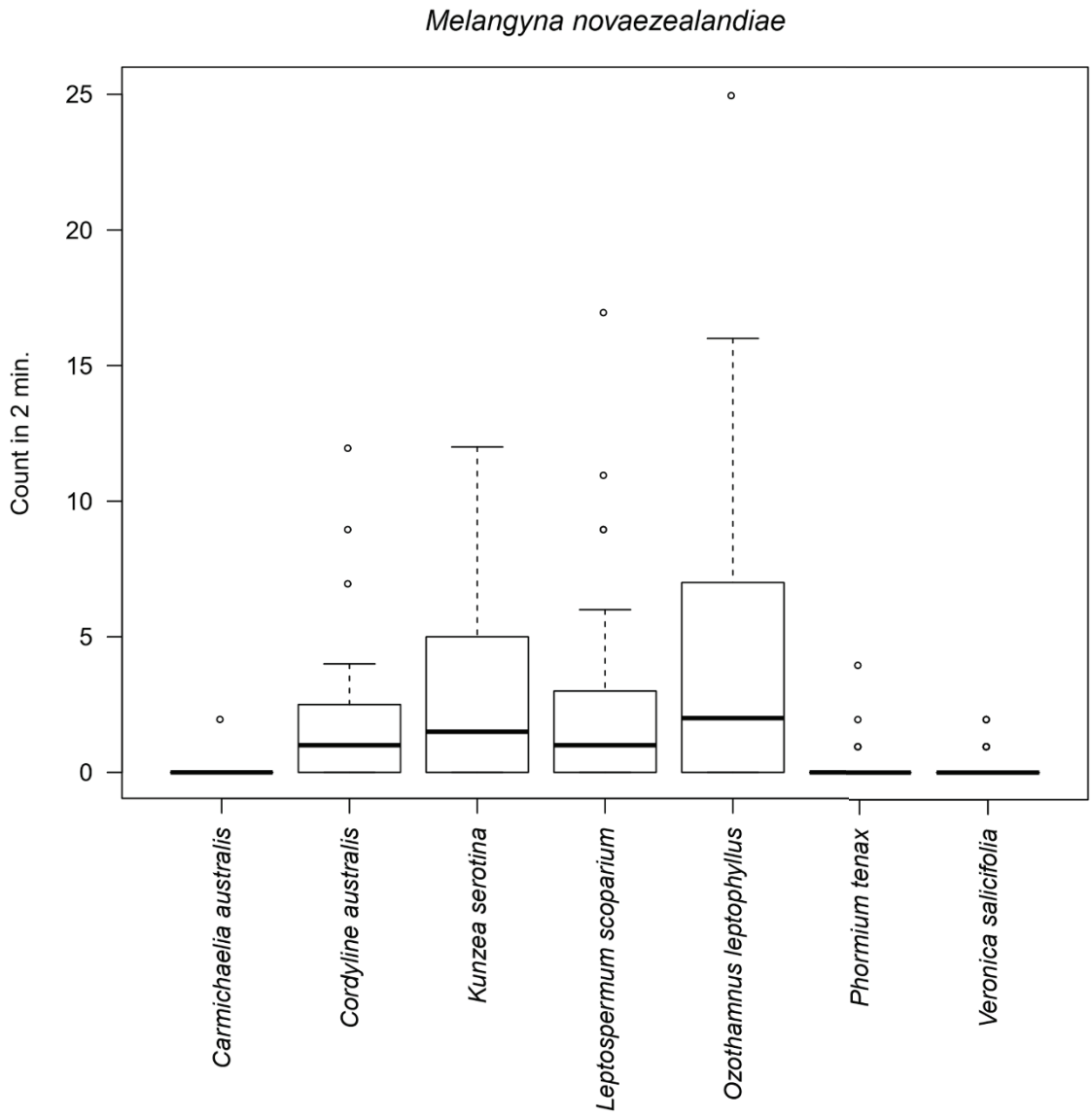


Figure 4-5 *Melangyna novaezealandiae* was also a generalist flower visitor, visiting all seven native plant species, although some species were visited more than others.

Dilophus nigrostigma abundance was significantly affected by property, date, plant, temperature, light and the interactions between temperature and humidity, temperature and wind, and between humidity and light (Table 4-8) This model explains a majority of the variation in *Dilophus nigrostigma* counts, having an R^2 of 0.96. *Dilophus nigrostigma* was only present in a short window of time, from the end of November until mid-December (Fig. 4-2). *Dilophus nigrostigma* counts were higher with higher temperature and less light.

Dilophus nigrostigma abundance differ significantly among plant species (Table 4-9, Fig. 4-7). Signifcantly more numbers were seen on *Cordyline australis* as oppose to *Carmichelia australis, Leptospermum scoparium, Ozothamnus leptophyllus* and *Phormium tenax.* It was more often observed on *Carmichelia australis* than *Leptospermum scoparium.*

Table 4-8 **(a)** ANOVA tables of the GLM of *Dilophus nigrostigma* abundance by property, date, plant species, temperature, humidity, maximum wind speed, light towards sun, and the interactions between the weather variables. I((Date)^2) allows the effect of date on abundance to curve up or down over the season. Bold figures indicate p<0.05. **(b)** The estimates of the poisson GLM model, predicting the log of *Dilophus nigrostigma* abundance.

a)

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL	NA	NA	251	972.503	NA
property	2	85.800	249	886.703	**0.000**
Date	1	264.057	248	622.646	**0.000**
I((Date)^2)	1	137.471	247	485.175	**0.000**
plant_sciname	6	128.346	241	356.829	**0.000**
Temperature	1	6.927	240	349.902	**0.008**
Humidity	1	0.010	239	349.891	0.919
Wind.max	1	2.410	238	347.481	0.121
Light.sun	1	14.369	237	333.112	**0.000**
Temperature:Humidity	1	40.592	236	292.520	**0.000**
Temperature:Wind.max	1	8.398	235	284.122	**0.004**
Temperature:Light.sun	1	46.464	234	237.658	**0.000**
Humidity:Wind.max	1	0.000	233	237.658	1.000
Humidity:Light.sun	1	0.000	232	237.658	1.000
Wind.max:Light.sun	1	0.000	231	237.658	1.000

b)

	Estimate
Intercept	1832.899
Farm 3	49.655
Farm 2	-18.452
Date	-10.887
I((Date)^2)	0.013
plant_scinameCordyline australis	3.519
plant_scinameKunzea	3.759
plant_scinameLeptospermum scoparium	2.180
plant_scinameOzothamnus leptophyllus	1.266
plant_scinamePhormium tenax	2.047
plant_scinameVeronic salicifolia	-58.006
Temperature	16.984
Humidity	7.241
Wind.max	56.654
Light.sun	-0.939
Temperature:Humidity	-0.354
Temperature:Wind.max	-1.736
Temperature:Light.sun	0.023
Humidity:Wind.max	-0.260
Humidity:Light.sun	0.008
Wind.max:Light.sun	-0.005

Table 4-9 Post hoc pairwise comparison of *Dilophus nigrostigma* abundance among plant species were calculated using the glht function with the Tukey method.

	Estimate	Std. Error	z value	Pr(>|z|)
Cordyline australis - Carmichaelia australis	3.519	0.5728	-6.577	<0.001
Kunzea - Carmichaelia australis	3.759	0.3787	-4.604	<0.001
Leptospermum scoparium - Carmichaelia australis	2.180	0.338	-5.506	<0.001
Ozothamnus leptophyllus - Carmichaelia australis	1.266	0.4837	-6.069	<0.001
Phormium tenax - Carmichaelia australis	2.047	0.4744	-7.067	<0.001
Veronica salicifolia - Carmichaelia australis	-58.006	0.6234	-2.539	0.128
Kunzea - Cordyline australis	0.240	0.6848	2.956	0.0426
Leptospermum scoparium - Cordyline australis	-1.339	0.6362	2.996	0.0380
Ozothamnus leptophyllus - Cordyline australis	-2.253	0.7731	1.076	0.9224
Phormium tenax - Cordyline australis	-1.472	0.6771	0.613	0.9955
Veronica salicifolia - Cordyline australis	-61.525	0.8781	2.488	0.1445
Leptospermum scoparium - Kunzea	-1.579	0.4949	-0.238	1
Ozothamnus leptophyllus - Kunzea	-2.493	0.5236	-2.277	0.229
Phormium tenax - Kunzea	-1.712	0.5916	-2.72	0.0817
Veronica salicifolia - Kunzea	-61.766	0.5505	0.292	0.9999
Ozothamnus leptophyllus - Leptospermum scoparium	-0.914	0.5798	-1.853	0.4742
Phormium tenax - Leptospermum scoparium	-0.133	0.561	-2.659	0.0952
Veronica salicifolia - Leptospermum scoparium	-60.187	0.7028	0.396	0.9996
Phormium tenax - Ozothamnus leptophyllus	0.781	0.6671	-0.626	0.995
Veronica salicifolia - Ozothamnus leptophyllus	-59.273	0.6119	2.21	0.2604
Veronica salicifolia - Phormium tenax	-60.054	0.7831	2.26	0.2361

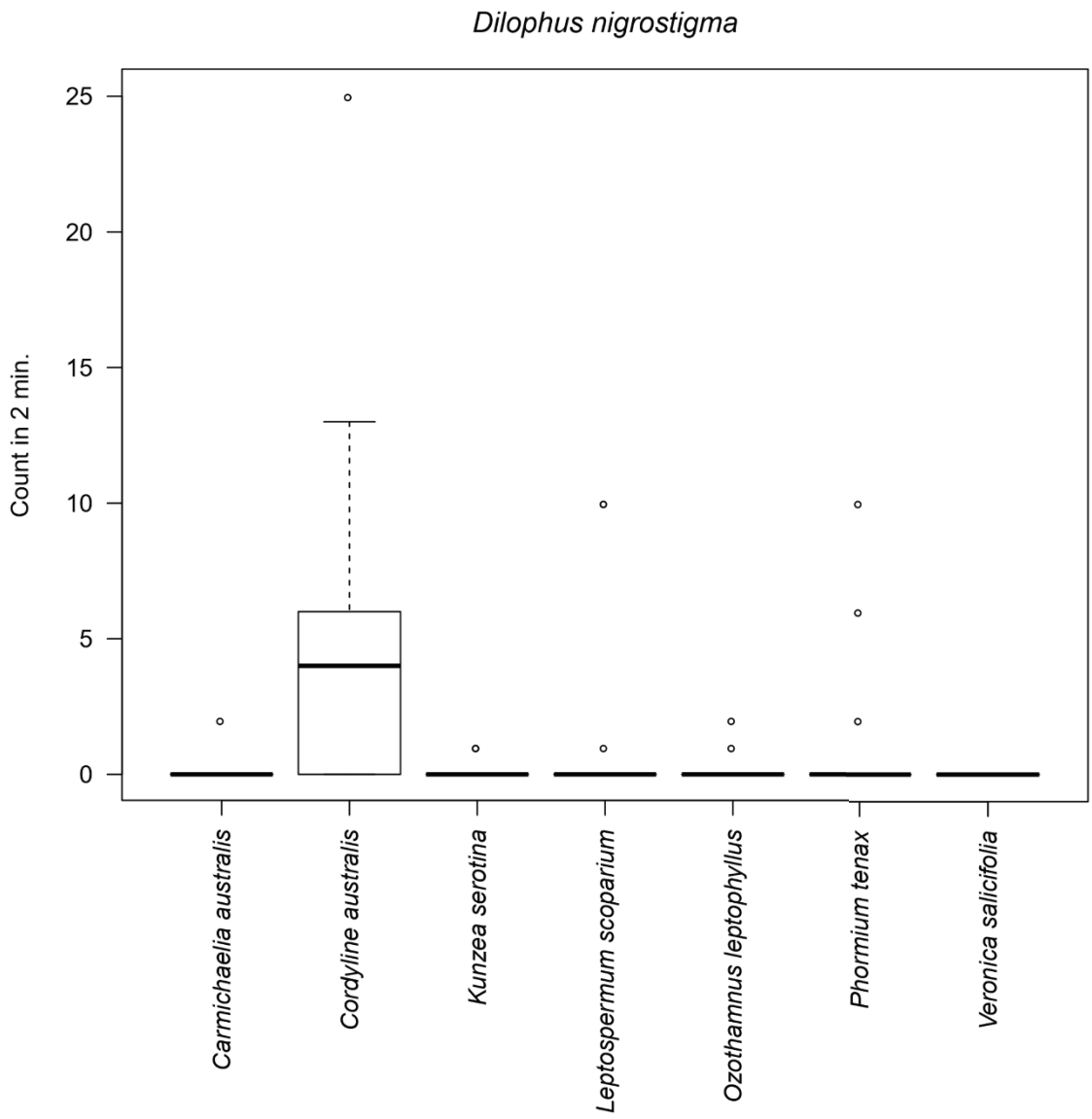


Figure 4-6 *Dilophus nigrostigma* was visiting 6 spieces, but was seen mainly on *Cordyline australis* where it was prolific.

Counts of ***Eristalis tenax***, were significantly affected by property, date, humidity, wind, light and plants species. The temperature effect was barely (p=0.057) insignificant. There were no significant interactions for *Eristalis tenax* (Table 4-10). The GLM explains the majority of the variation in *Eristalis tenax* counts, having an R2 of 0.70.

Eristalis tenax were missing in the very early observations but then persisted through the season with a brief dip at the end of December (Fig. 4-2). *Eristalis tenax* counts were higher with higher humidity, less wind and lighter conditions.

Eristalis tenax was seen on five of the seven plant species (Table 4-11, Fig. 4-7). Among these five, it was seen significantly more often on *Veronica salicifolia* than *Ozothamnus leptophyllus, Leptospermum scoparium* and *Kunzea serotina.*

Table 4-10 **(a)** ANOVA tables of the GLM of *Eristalis tenax* abundance by property, date, plant species, temperature, humidity, maximum wind speed, light towards sun, and the interactions between the weather variables. I((Date)^2) allows the effect of date on abundance to curve up or down over the season. Bold figures indicate p<0.05. **(b)** The estimates of the poisson GLM model, predicting the log of *Eristalis tenax* abundance.

a)

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL	NA	NA	251	373.611	NA
property	2	56.588	249	317.024	**0.000**
Date	1	12.230	248	304.794	**0.000**
I((Date)^2)	1	1.260	247	303.534	0.262
plant_sciname	6	83.662	241	219.872	**0.000**
Temperature	1	3.615	240	216.258	0.057
Humidity	1	8.032	239	208.226	**0.005**
Wind.max	1	7.019	238	201.207	**0.008**
Light.sun	1	11.249	237	189.958	**0.001**
Temperature:Humidity	1	1.798	236	188.160	0.180
Temperature:Wind.max	1	0.019	235	188.141	0.890
Temperature:Light.sun	1	1.829	234	186.312	0.176
Humidity:Wind.max	1	0.702	233	185.610	0.402
Humidity:Light.sun	1	5.574	232	180.036	**0.018**
Wind.max:Light.sun	1	4.875	231	175.161	**0.027**

b)

	Estimate
Intercept	-79.015
Farm 3	-0.653
Farm 2	-2.025
Date	0.299
I((Date)^2)	-0.001
plant_scinameCordyline australis	18.480
plant_scinameKunzea	18.078
plant_scinameLeptospermum scoparium	17.559
plant_scinameOzothamnus leptophyllus	18.465
plant_scinamePhormium tenax	-0.103
plant_scinameVeronic salicifolia	21.046
Temperature	0.165
Humidity	0.358
Wind.max	-1.589
Light.sun	0.020
Temperature:Humidity	-0.004
Temperature:Wind.max	0.022
Temperature:Light.sun	0.000
Humidity:Wind.max	0.015
Humidity:Light.sun	0.000
Wind.max:Light.sun	0.000

Table 4-11 Post hoc pairwise comparison of *Eristalis tenax* abundance among plant species were calculated using the glht function with the Tukey method.

	Estimate	Std. Error	z value	Pr(>|z|)
Cordyline australis - Carmichaelia australis	18.480	1884.095	0.010	1.000
Kunzea - Carmichaelia australis	18.078	1884.095	0.010	1.000
Leptospermum scoparium - Carmichaelia australis	17.559	1884.095	0.009	1.000
Ozothamnus leptophyllus - Carmichaelia australis	18.465	1884.095	0.010	1.000
Phormium tenax - Carmichaelia australis	-0.103	2448.689	0.000	1.000
Veronica salicifolia - Carmichaelia australis	21.046	1884.095	0.011	1.000
Kunzea - Cordyline australis	-0.401	0.840	-0.478	0.999
Leptospermum scoparium - Cordyline australis	-0.920	0.485	-1.899	0.386
Ozothamnus leptophyllus - Cordyline australis	-0.015	0.559	-0.026	1.000
Phormium tenax - Cordyline australis	-18.583	1564.055	-0.012	1.000
Veronica salicifolia - Cordyline australis	2.566	0.956	2.683	**0.069**
Leptospermum scoparium - Kunzea	-0.519	0.892	-0.582	0.996
Ozothamnus leptophyllus - Kunzea	0.387	0.807	0.479	0.998
Phormium tenax - Kunzea	-18.182	1564.055	-0.012	1.000
Veronica salicifolia - Kunzea	2.967	0.989	3.001	**0.027**
Ozothamnus leptophyllus - Leptospermum scoparium	0.906	0.644	1.406	0.728
Phormium tenax - Leptospermum scoparium	-17.662	1564.055	-0.011	1.000
Veronica salicifolia - Leptospermum scoparium	3.487	0.992	3.516	**0.005**
Phormium tenax - Ozothamnus leptophyllus	-18.568	1564.055	-0.012	1.000
Veronica salicifolia - Ozothamnus leptophyllus	2.581	0.746	3.459	**0.006**
Veronica salicifolia - Phormium tenax	21.149	1564.055	0.014	1.000

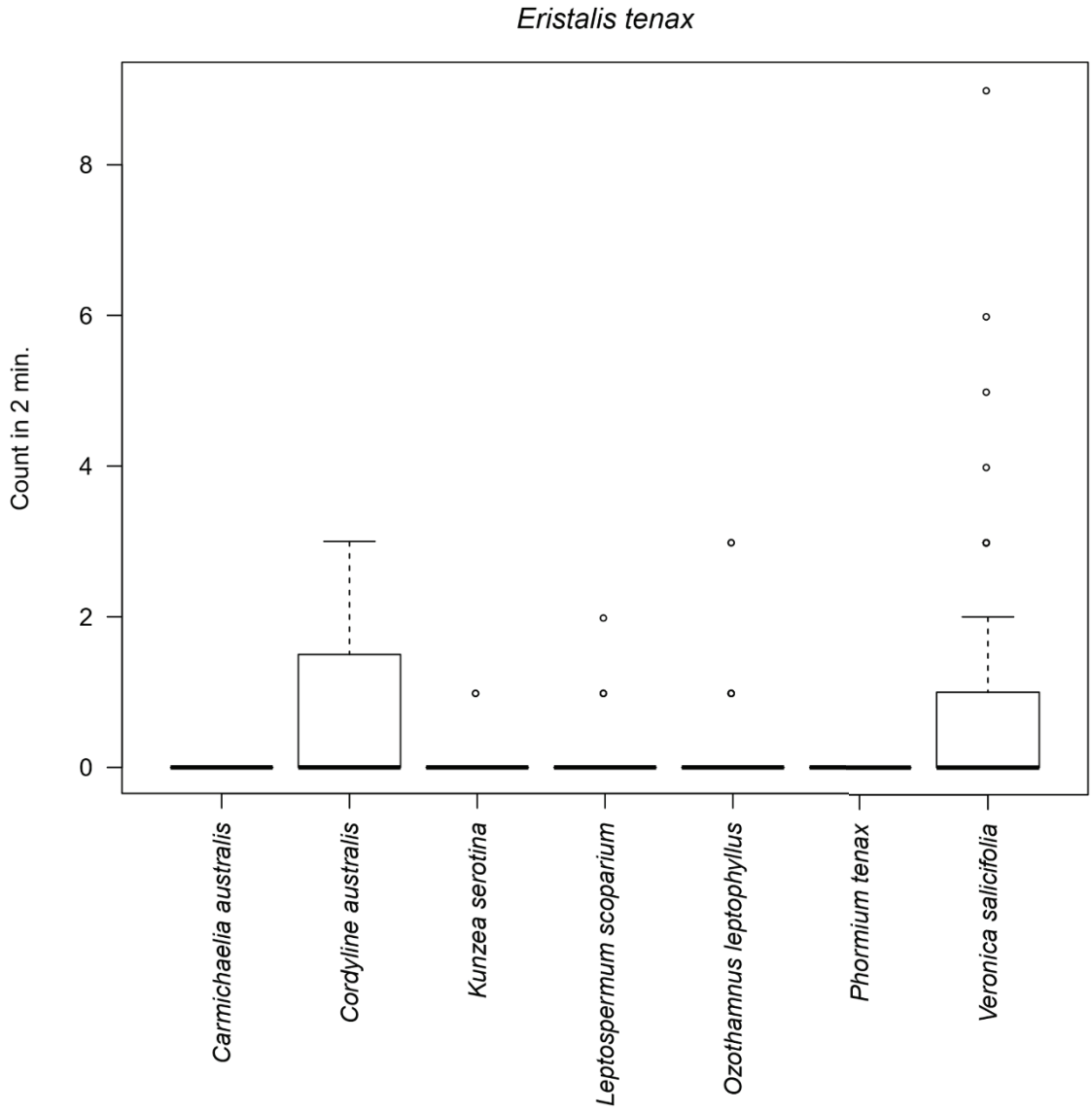


Figure 4-7 *Eristalis tenax* was visiting 5 spieces, but *Cordyline australis* and *Veronica salicifolia* was the most visited

Counts of ***Calliphora vicina*** were significantly affected by all variables except the interactions between temperature and wind, humidity and wind, and wind and light (Table 4-12) The GLM explained the majority of the variation in *Calliphora vicina* counts, having an R2 of 0.88.

Only two significant differences between plant species were observed for *Calliphora vicina*. More indiviudals were observed on *C. australis* and *L. scoparium* than on *P. tenax* (Table 4-13, Fig.4-8).

Calliphora vicina flies were present during the whole season, with a peak end of November (Fig. 4-2). *Calliphora vicina* counts were higher with higher temperature, humidity and light but with lower wind (Table 4-12 b)).

Table 4-12 **(a)**ANOVA tables of the GLM of *Calliphora vicina* abundance by property, date, plant species, temperature, humidity, maximum wind speed, light towards sun, and the interactions between the weather variables. I((Date)^2) allows the effect of date on abundance to curve up or down over the season. Bold figures indicate p<0.05. **(b)** The estimates of the poisson GLM model, predicting the log of *Calliphora vicina* abundance.

a)

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL	NA	NA	251	705.731	NA
property	2	104.414	249	601.317	**0.000**
Date	1	92.067	248	509.251	**0.000**
I((Date)^2)	1	1.159	247	508.092	0.282
plant_sciname	6	123.153	241	384.939	**0.000**
Temperature	1	23.510	240	361.429	**0.000**
Humidity	1	12.321	239	349.108	**0.000**
Wind.max	1	39.971	238	309.137	**0.000**
Light.sun	1	11.420	237	297.717	**0.001**
Temperature:Humidity	1	8.968	236	288.749	**0.003**
Temperature:Wind.max	1	1.889	235	286.860	0.169
Temperature:Light.sun	1	9.887	234	276.973	**0.002**
Humidity:Wind.max	1	1.000	233	275.973	0.317
Humidity:Light.sun	1	16.716	232	259.257	**0.000**
Wind.max:Light.sun	1	0.054	231	259.202	0.816

b)

	Estimate
Intercept	26.330
Farm 3	-2.541
Farm 2	-0.999
Date	-0.348
I((Date)^2)	0.000
plant_scinameCordyline australis	18.809
plant_scinameKunzea	16.982
plant_scinameLeptospermum scoparium	18.383
plant_scinameOzothamnus leptophyllus	17.857
plant_scinamePhormium tenax	16.389
plant_scinameVeronic salicifolia	17.335
Temperature	0.583
Humidity	0.356
Wind.max	-3.419
Light.sun	0.043
Temperature:Humidity	-0.007
Temperature:Wind.max	0.082
Temperature:Light.sun	-0.001
Humidity:Wind.max	0.026
Humidity:Light.sun	0.000
Wind.max:Light.sun	0.000

Table 4-13 Post hoc pairwise comparison of *Calliphora vicina* abundance among plant species were calculated using the glht function with the Tukey method.

	Estimate	Std. Error	z value	Pr(>|z|)
Cordyline australis - Carmichaelia australis	18.809	1019.088	0.018	1.000
Kunzea - Carmichaelia australis	16.983	1019.088	0.017	1.000
Leptospermum scoparium - Carmichaelia australis	18.384	1019.088	0.018	1.000
Ozothamnus leptophyllus - Carmichaelia australis	17.857	1019.088	0.018	1.000
Phormium tenax - Carmichaelia australis	16.389	1019.088	0.016	1.000
Veronica salicifolia - Carmichaelia australis	17.335	1019.088	0.017	1.000
Kunzea - Cordyline australis	-1.826	0.757	-2.414	0.141
Leptospermum scoparium - Cordyline australis	-0.425	0.202	-2.105	0.274
Ozothamnus leptophyllus - Cordyline australis	-0.952	0.439	-2.169	0.242
Phormium tenax - Cordyline australis	-2.420	0.447	-5.412	**<0.001**
Veronica salicifolia - Cordyline australis	-1.473	0.718	-2.051	0.304
Leptospermum scoparium - Kunzea	1.401	0.750	1.868	0.416
Ozothamnus leptophyllus - Kunzea	0.874	0.782	1.119	0.890
Phormium tenax - Kunzea	-0.594	0.836	-0.711	0.988
Veronica salicifolia - Kunzea	0.353	0.926	0.381	1.000
Ozothamnus leptophyllus - Leptospermum scoparium	-0.527	0.437	-1.204	0.851
Phormium tenax - Leptospermum scoparium	-1.995	0.438	-4.552	**<0.001**
Veronica salicifolia - Leptospermum scoparium	-1.048	0.724	-1.447	0.708
Phormium tenax - Ozothamnus leptophyllus	-1.468	0.555	-2.644	0.079
Veronica salicifolia - Ozothamnus leptophyllus	-0.522	0.575	-0.907	0.957
Veronica salicifolia - Phormium tenax	0.947	0.797	1.187	0.859

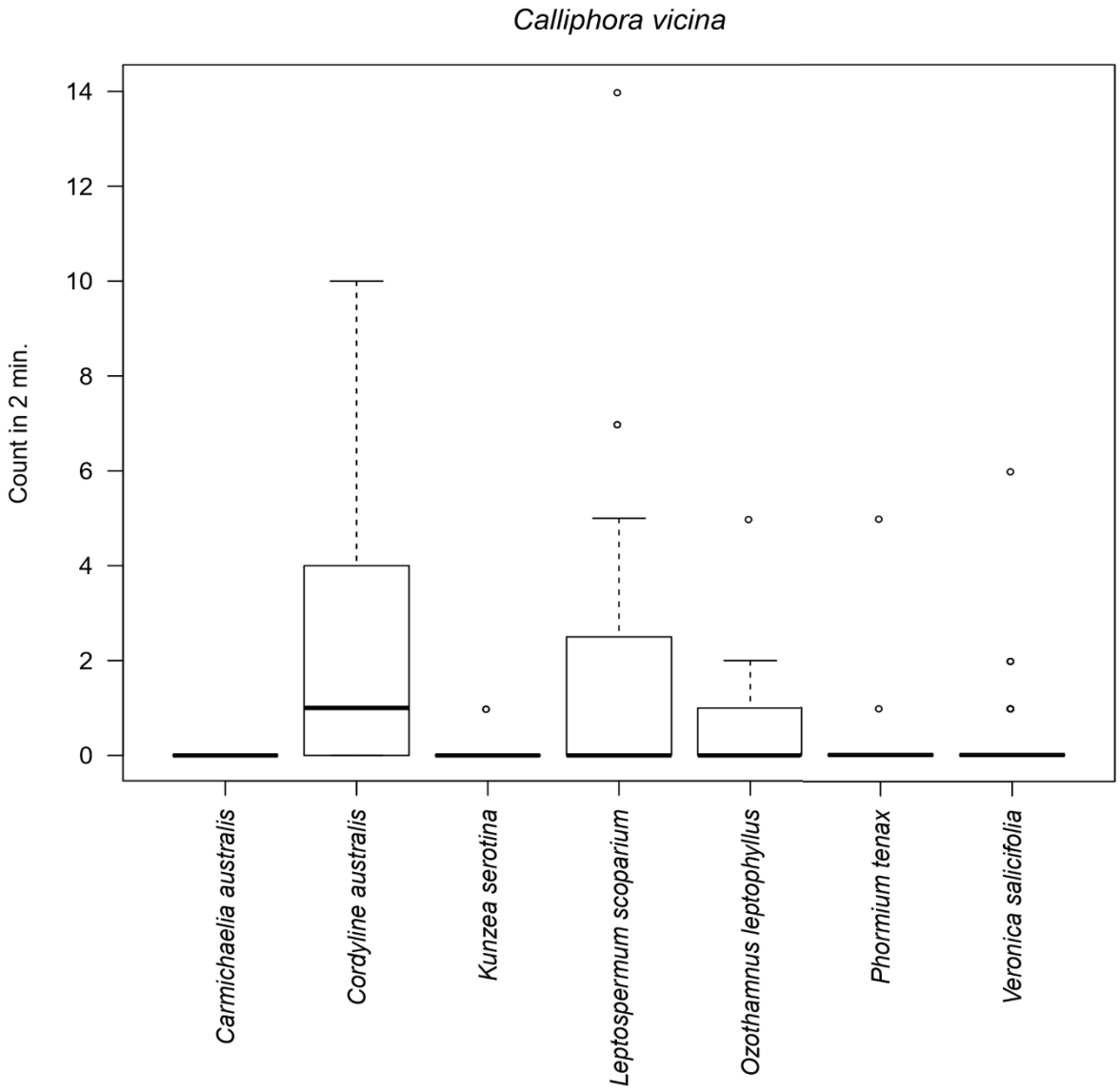


Figure 4-8 *Calliphora vicina* was visiting 6 of 7 spieces, with *Cordyline australis* the most.

Calliphora stygia abundance was significantly affected by property, date, plant, temperature and wind and the interactions between temperature and humidity and temperature and light and between humidity and light (Table 4-14). This GLM explained the majority of the variation in *Calliphora stygia* counts, having an R^2 of 0.99. *Calliphora stygia* was only present in the plantings for a short period, from November until mid-December with a tiny reappearance at the end of January on a *Veronica salicifolia* (Fig. 4-2). *Calliphora stygia* counts were higher with lower temperature and lower wind (Table 4-14 b)).

Calliphora stygia abundance differed significantly among plant species (Table 4-15, Fig. 4-9). It was seen signfiicantly more often on *Cordyline australis than Leptospermum scoparium* and *Phormium tenax. Leptospermum scoparium* was more often visited than *Phormium tenax.*

Table 4-14 **(a)**ANOVA tables of the GLM of *Calliphora stygia* abundance by property, date, plant species, temperature, humidity, maximum wind speed, light towards sun, and the interactions between the weather variables. I((Date)^2) allows the effect of date on abundance to curve up or down over the season. Bold figures indicate p<0.05. **(b)** The estimates of the poisson GLM model, predicting the log of *Calliphora stygia* abundance.

a)

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL	NA	NA	251	1261.137	NA
property	2	235.284	249	1025.853	**0.000**
Date	1	397.270	248	628.583	**0.000**
I((Date)^2)	1	85.445	247	543.137	**0.000**
plant_sciname	6	118.733	241	424.404	**0.000**
Temperature	1	187.349	240	237.055	**0.000**
Humidity	1	0.042	239	237.013	0.838
Wind.max	1	65.603	238	171.411	**0.000**
Light.sun	1	1.003	237	170.408	0.317
Temperature:Humidity	1	3.757	236	166.651	0.053
Temperature:Wind.max	1	2.256	235	164.395	0.133
Temperature:Light.sun	1	8.954	234	155.441	**0.003**
Humidity:Wind.max	1	1.174	233	154.267	0.279
Humidity:Light.sun	1	4.737	232	149.530	**0.030**
Wind.max:Light.sun	1	1.349	231	148.181	0.245

b)

	Estimate
intercept	2217.200
Farm 3	21.863
Farm 2	5.923
Date	-12.831
I((Date)^2)	0.018
plant_scinameCordyline australis	23.170
plant_scinameHebe salicifolia	-45.187
plant_scinameKunzea	1.227
plant_scinameLeptospermum scoparium	21.257
plant_scinameOzothamnus leptophyllus	23.367
plant_scinamePhormium tenax	19.992
Temperature	-18.374
Humidity	3.710
Wind.max	-0.862
Light.sun	-0.090
Temperature:Humidity	0.215
Temperature:Wind.max	-1.208
Temperature:Light.sun	0.017
Humidity:Wind.max	-0.197
Humidity:Light.sun	-0.006
Wind.max:Light.sun	0.035

Table 4-15 Post hoc pairwise comparison of *Calliphora stygia* abundance among plant species were calculated using the glht function with the Tukey method.

	Estimate	Std. Error	z value	Pr(>|z|)
ordyline australis - Carmichaelia australis	23.171	12288.932	0.002	1
Kunzea - Carmichaelia australis	1.227	17281.770	0.000	1
Leptospermum scoparium - Carmichaelia australis	21.257	12288.932	0.002	1
Ozothamnus leptophyllus - Carmichaelia australis	23.367	12288.932	0.002	1
Phormium tenax - Carmichaelia australis	19.992	12288.932	0.002	1
Veronica salicifolia - Carmichaelia australis	-45.188	13466.580	-0.003	1
Kunzea - Cordyline australis	-21.944	12150.791	-0.002	1
Leptospermum scoparium - Cordyline australis	-1.914	0.284	-6.734	**<0.01**
Ozothamnus leptophyllus - Cordyline australis	0.197	0.689	0.286	1
Phormium tenax - Cordyline australis	-3.179	1.079	-2.947	**0.028**
Veronica salicifolia - Cordyline australis	-68.358	5507.351	-0.012	1
Leptospermum scoparium - Kunzea	20.030	12150.791	0.002	1
Ozothamnus leptophyllus - Kunzea	22.141	12150.791	0.002	1
Phormium tenax - Kunzea	18.765	12150.791	0.002	1
Veronica salicifolia - Kunzea	-46.414	13340.639	-0.003	1
Ozothamnus leptophyllus - Leptospermum scoparium	2.110	0.738	2.859	**0.037**
Phormium tenax - Leptospermum scoparium	-1.265	1.071	-1.181	0.845
Veronica salicifolia - Leptospermum scoparium	-66.444	5507.352	-0.012	1
Phormium tenax - Ozothamnus leptophyllus	-3.376	1.254	-2.693	0.059
Veronica salicifolia - Ozothamnus leptophyllus	-68.555	5507.351	-0.012	1
Veronica salicifolia - Phormium tenax	-65.179	5507.352	-0.012	1

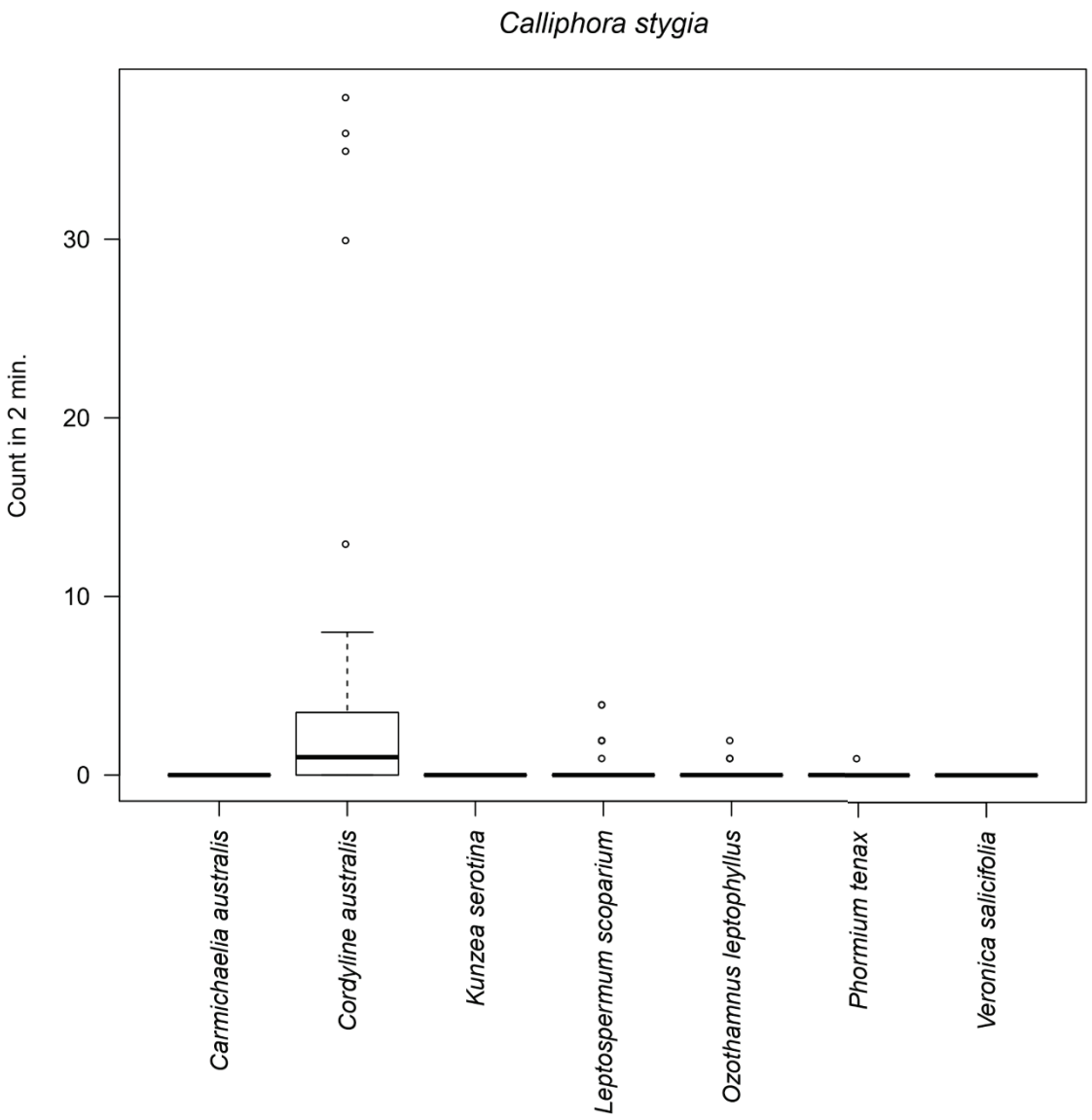


Figure 4-9 *Calliphora stygia* was recorded on four of seven plant species and only on Cordyline australis with significance.

***Leioproctus* spp**. abundance was significantly affected by property, date, plant, wind and the interactions between temperature and humidity and the interaction between humidity and light, and humidity and wind (Table 4-16). This GLM explained a majority of the variation in *Leioproctus* spp. counts, having an R^2 of 0.83.

Leioproctus spp. abundance was highest from mid-November until beginning of December, but was recorded back in January, with lesser abundance (Fig. 4-2). The only significant weather variable was the wind. The insects were positively affected by wind.

Leioproctus spp. showed clear preference among flowering plant species (Table 4-17, Fig. 4-10). More indiviudals were observed on *Carmichaelia australis* than *Cordyline australis, K. serotina,*

L. scoparium and more on *P. tenax*, *Cordyline australis* than on *K. serotina* and *L. scoparium.*

Table 4-16 **(a)**ANOVA tables of the GLM of *Leioproctus* spp.abundance by property, date, plant species, temperature, humidity, maximum wind speed, light towards sun, and the interactions between the weather variables. I((Date)^2) allows the effect of date on abundance to curve up or down over the season. Bold figures indicate p<0.05 **(b)** The estimates of the poisson GLM model, predicting the log of *Leioproctus* spp. abundance.

a)

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL	NA	NA	251	686.1069	NA
property	2	77.563	249	608.543	**0.000**
Date	1	4.173	248	604.371	**0.041**
I((Date)^2)	1	7.383	247	596.988	**0.007**
plant_sciname	6	232.382	241	364.606	**0.000**
Temperature	1	3.230	240	361.376	0.072
Humidity	1	3.404	239	357.972	0.065
Wind.max	1	15.162	238	342.810	**0.000**
Light.sun	1	0.756	237	342.054	0.385
Temperature:Humidity	1	16.800	236	325.254	**0.000**
Temperature:Wind.max	1	1.321	235	323.934	0.250
Temperature:Light.sun	1	2.266	234	321.668	0.132
Humidity:Wind.max	1	6.840	233	314.828	**0.009**
Humidity:Light.sun	1	12.780	232	302.048	**0.000**
Wind.max:Light.sun	1	1.482	231	300.566	0.223

b)

	Estimate
intercept	-23.679
Farm 3	2.984
Farm 2	1.429
Date	-0.033
I((Date)^2)	0.000
plant_scinameCordyline australis	-3.768
plant_scinameKunzea	-1.744
plant_scinameLeptospermum scoparium	-1.861
plant_scinameOzothamnus leptophyllus	-2.935
plant_scinamePhormium tenax	-3.353
plant_scinameVeronic salicifolia	-1.583
Temperature	0.916
Humidity	0.484
Wind.max	0.852
Light.sun	0.013
Temperature:Humidity	-0.012
Temperature:Wind.max	0.003
Temperature:Light.sun	0.000
Humidity:Wind.max	-0.012
Humidity:Light.sun	0.000
Wind.max:Light.sun	0.000

Table 4-17 Post hoc pairwise comparison of *Leioproctus* spp.abundance among plant species were calculated using the glht function with the Tukey method.

	Estimate	Std. Error	z value	Pr(>|z|)
Cordyline australis - Carmichaelia australis	-3.768	0.573	-6.577	<0.001
Kunzea - Carmichaelia australis	-1.744	0.379	-4.604	<0.001
Leptospermum scoparium - Carmichaelia australis	-1.861	0.338	-5.506	<0.001
Ozothamnus leptophyllus - Carmichaelia australis	-2.935	0.484	-6.069	<0.001
Phormium tenax - Carmichaelia australis	-3.353	0.474	-7.067	<0.001
Veronica salicifolia - Carmichaelia australis	-1.583	0.623	-2.539	0.128
Kunzea - Cordyline australis	2.024	0.685	2.956	0.043
Leptospermum scoparium - Cordyline australis	1.906	0.636	2.996	0.038
Ozothamnus leptophyllus - Cordyline australis	0.832	0.773	1.076	0.922
Phormium tenax - Cordyline australis	0.415	0.677	0.613	0.996
Veronica salicifolia - Cordyline australis	2.185	0.878	2.488	0.145
Leptospermum scoparium - Kunzea	-0.118	0.495	-0.238	1.000
Ozothamnus leptophyllus - Kunzea	-1.192	0.524	-2.277	0.229
Phormium tenax - Kunzea	-1.609	0.592	-2.720	0.082
Veronica salicifolia - Kunzea	0.161	0.551	0.292	1.000
Ozothamnus leptophyllus - Leptospermum scoparium	-1.074	0.580	-1.853	0.474
Phormium tenax - Leptospermum scoparium	-1.492	0.561	-2.659	0.095
Veronica salicifolia - Leptospermum scoparium	0.278	0.703	0.396	1.000
Phormium tenax - Ozothamnus leptophyllus	-0.417	0.667	-0.626	0.995
Veronica salicifolia - Ozothamnus leptophyllus	1.352	0.612	2.210	0.260
Veronica salicifolia - Phormium tenax	1.770	0.783	2.260	0.236

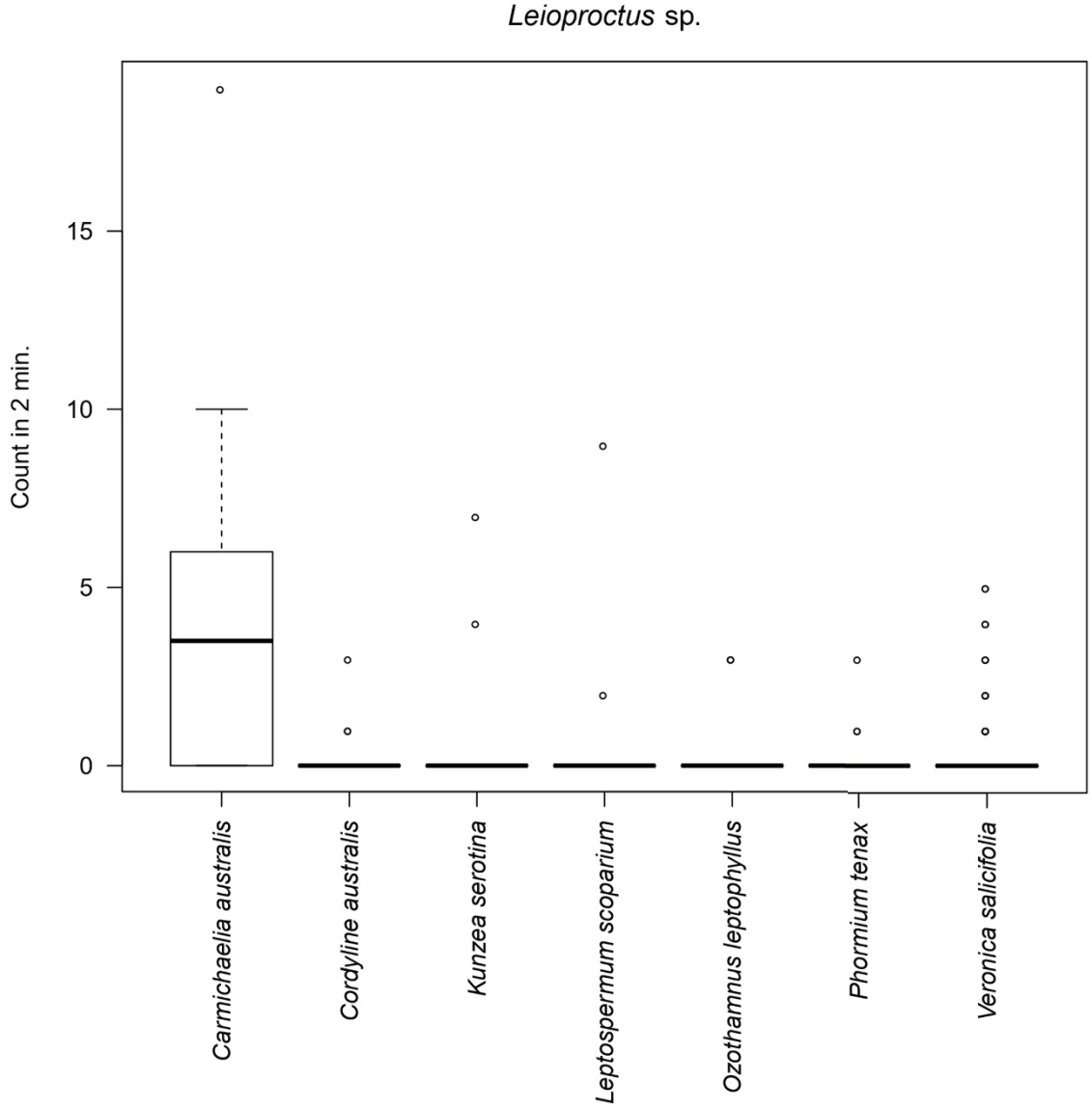


Figure 4-10 Although *Leioproctus* spp.was recorded on all eight plant species it mostly was visiting *Carmichaelia australis*

4.3.4 Environmental factors influencing insect composition

The results of four dimensional NMDS ordination are displayed in Fig. 4-11 and Fig. 4-12 along with vectors of the numerical environmental gradients. These figures also show which insect species were most associated with these environmental gradients. There were differences in insect composition among the different plant species (Fig. 4-11) and among the three surveyed properties (Fig. 4-12).

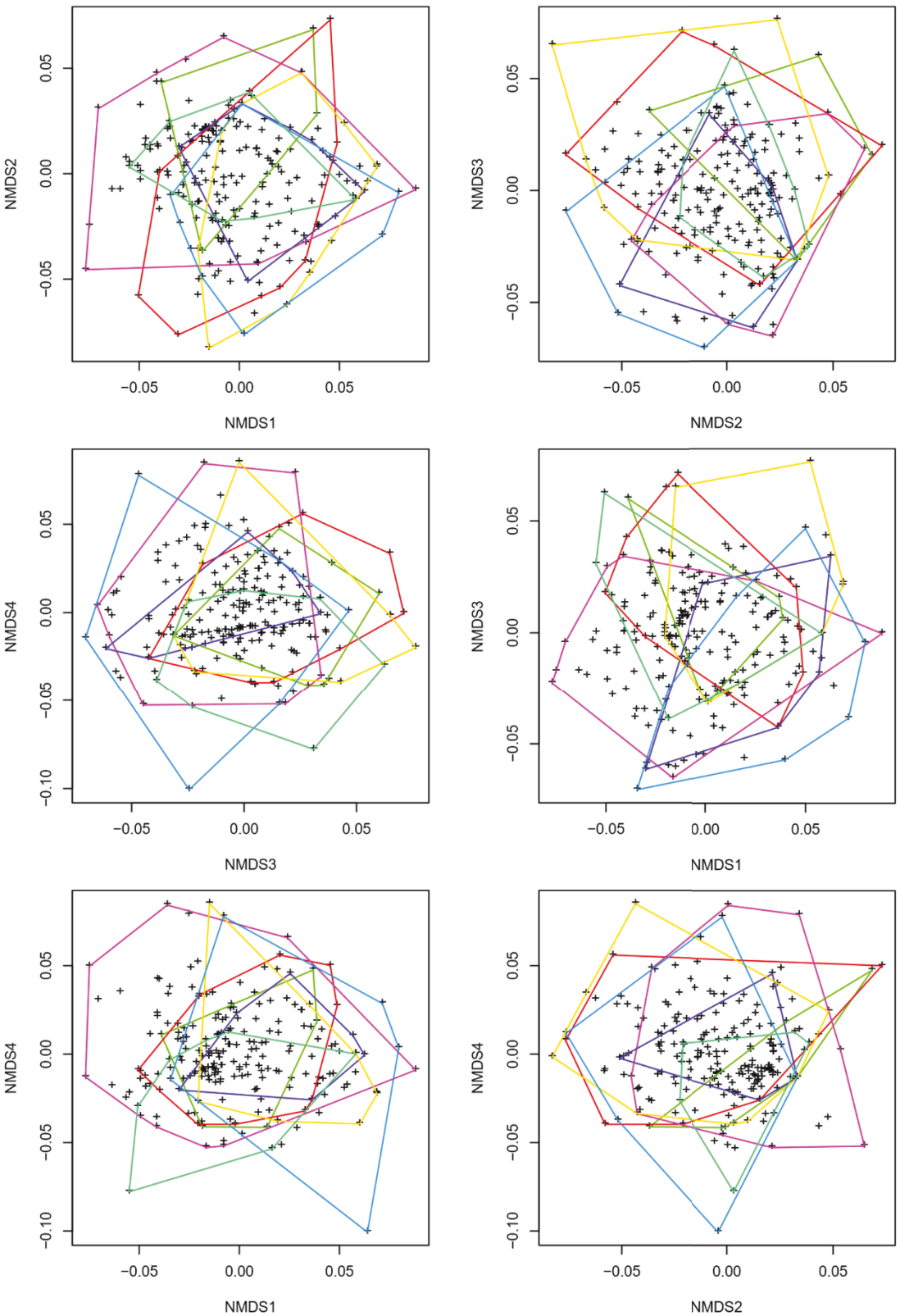


Figure 4-11 All axes of the four dimensional NMDS ordination of insect counts on flowers showing the hull polygons around the surveys from each plant species. Plant species had a significant affect on insect composition.The plant species are colour coded as follows: *Carmichaelia australis* = violet, *Cordyline australis* = purple, *Hebe salicifolia* = darkgreen, *Kunzea* = darkred, *Leptospermum scoparium* = darkorange, *Ozothamnus leptophyllus* = yellow, and *Phormium tenax* = brown

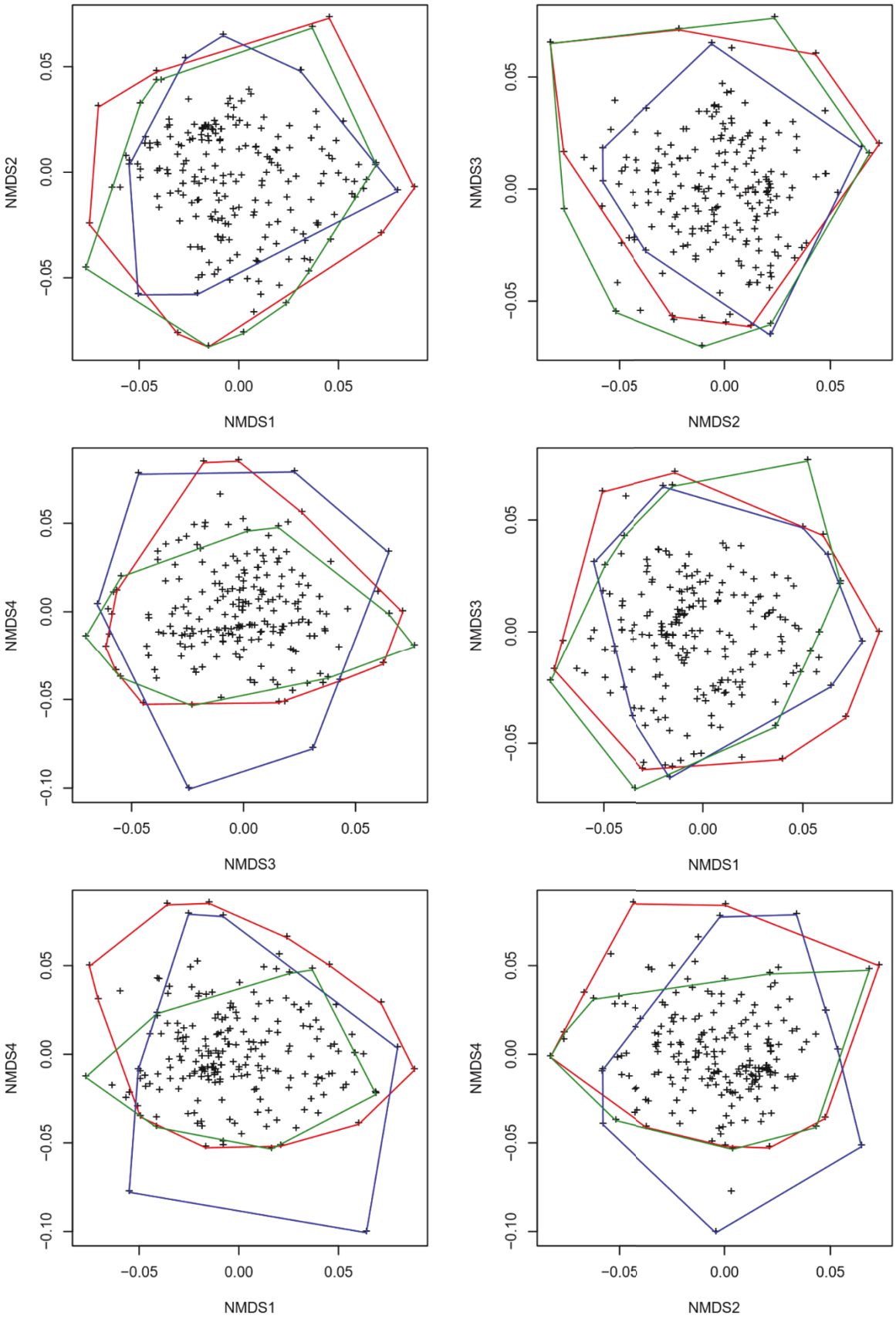


Figure 4-12 All axes of the four dimensional NMDS ordination of insect counts on flowers showing the hull polygons around the three farms surveyed. Farm had a significant affect on insect composition (see Table ADONIS). The farms are colour coded as follows: Farm 1 is forest green, Farm 2 is red, Farm 3 is blue.

The species composition of insect flower visitors in my surveys was affected by property, date, plant species, temperature, humidity, and wind speed, but notably not light (Table 4-18, Fig. 4-13). The effects of weather on insect species composition was also affected by what plant species they were visiting, as seen by the significant interactions between plants and variables such as temperature, humidity, wind, and light (Table 4-18).

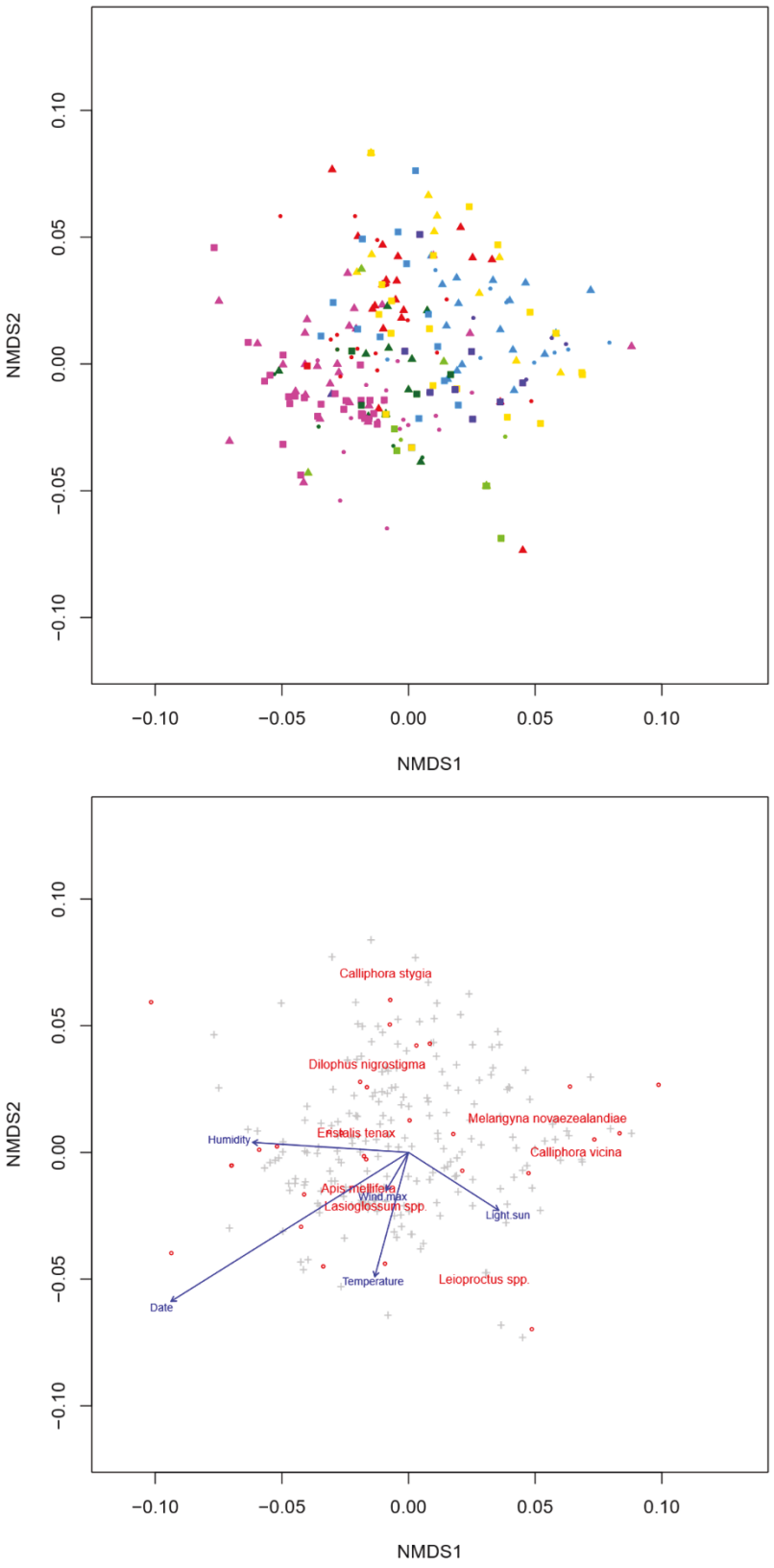
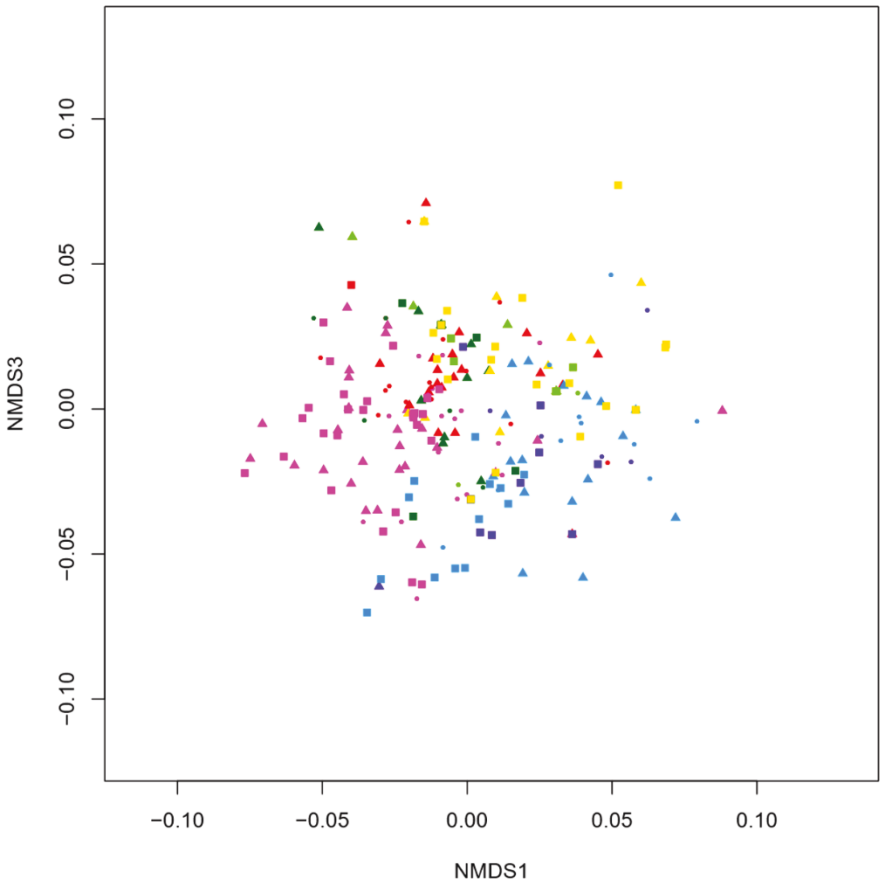
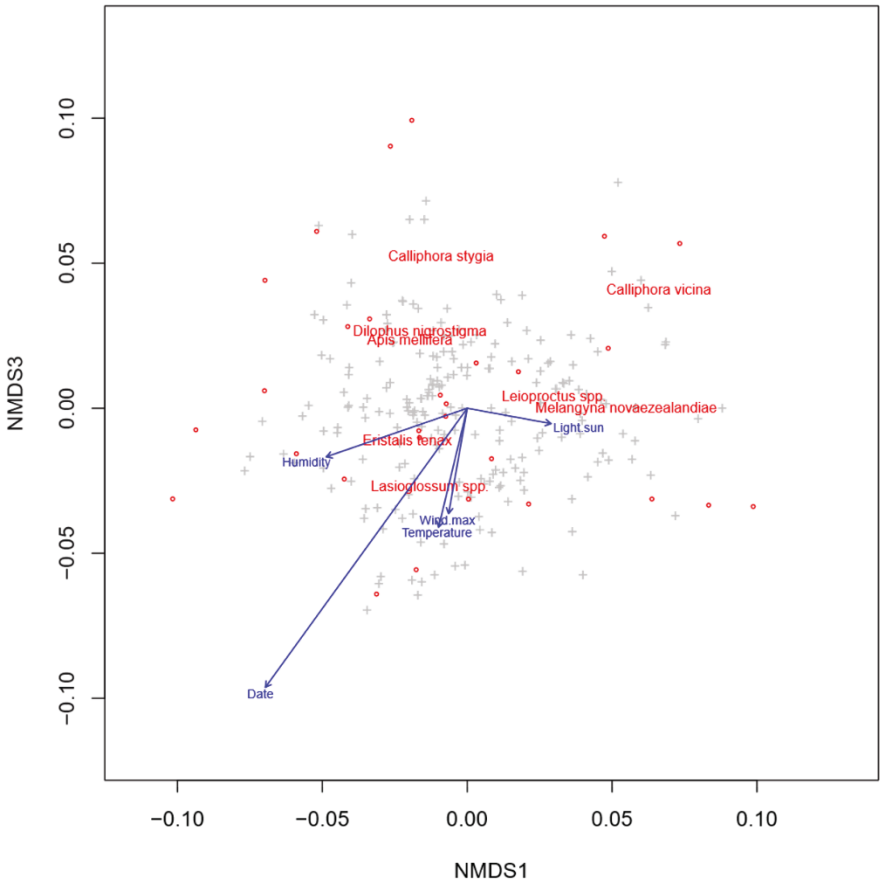


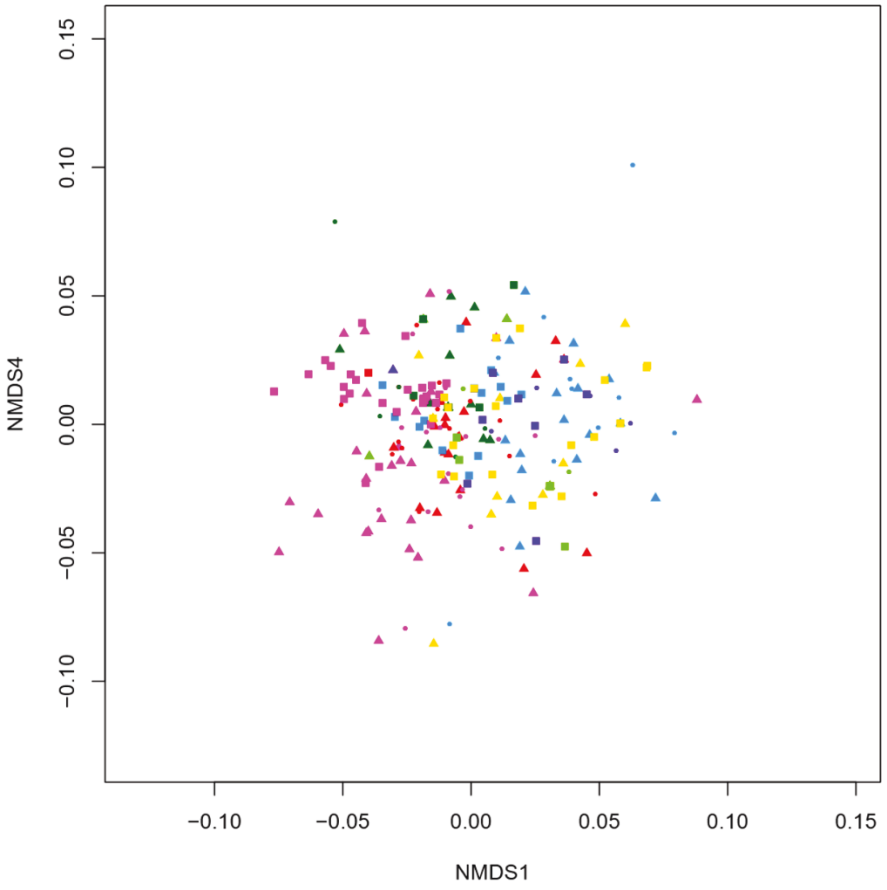
Figure 4-13 **a)** The results of the **four dimensional NMDS ordination** of insect flower visitors per two minute survey. Each of **(a)–(e)** displays the combination of two of the ordination axes. Top Plot: The plant species are colour coded as follows: *Carmichaelia australis* = violet, *Cordyline australis* = purple, *Hebe salicifolia* = darkgreen, *Kunzea* = darkred, *Leptospermum scoparium* = darkorange, *Ozothamnus leptophyllus* = yellow, and *Phormium tenax* = brown. Properties with three different symbols (Farm 1 = square, Farm 2 = triangle, and Farm 3 = circle). The bottom plot for each shows the same ordination points as grey "+" symbols with the insect species as red circles, with eight most abundant insect species labelled, and vectors showing the direction and magnitude of the environmental effects. See Methods for details.

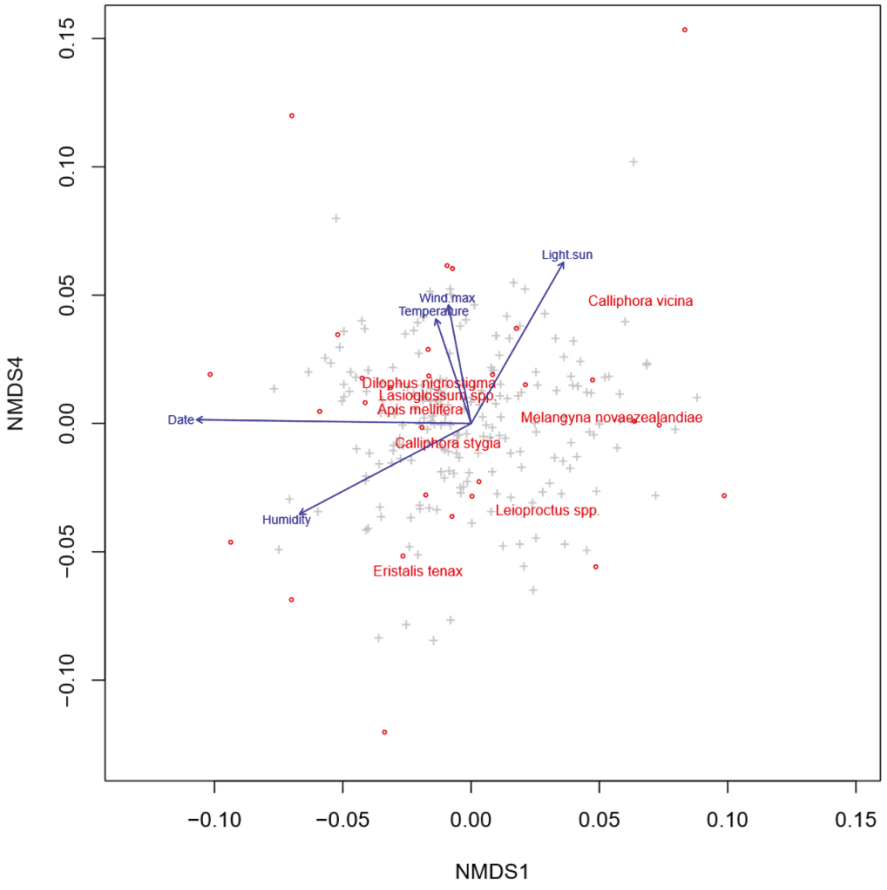
b)


NMDS3
0.10
0.05
0.00
−0.05
−0.10
−0.10
−0.05
0.00
0.05
0.10
NMDS1

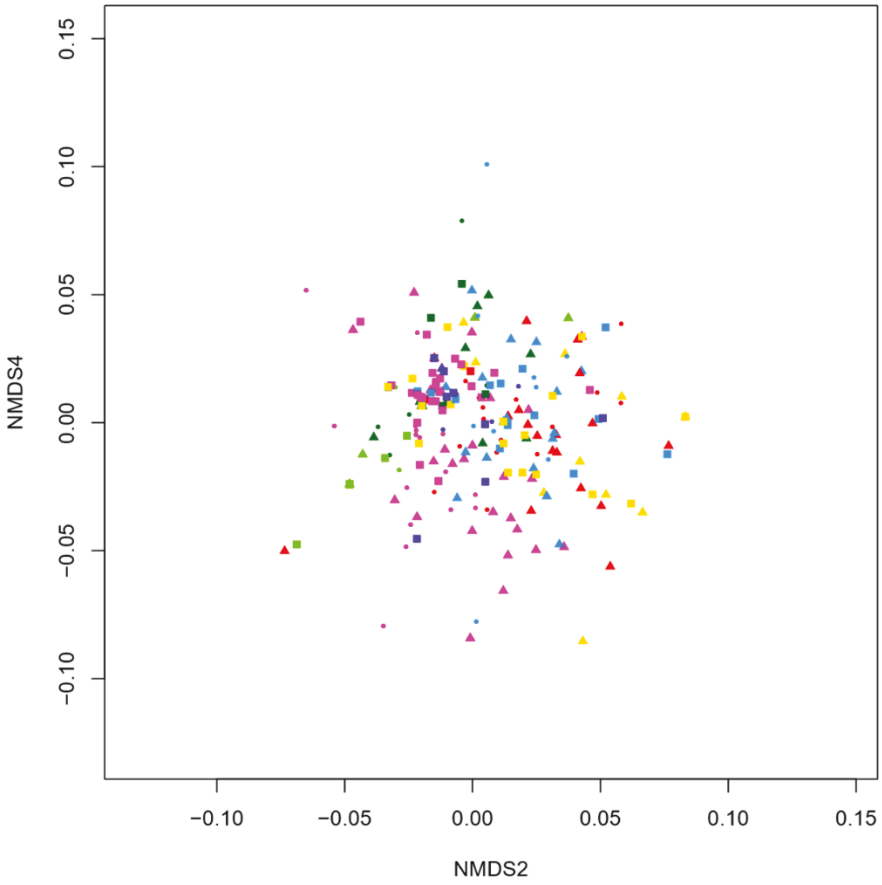

NMDS3
0.10
0.05
0.00
−0.05
−0.10
Calliphora stygia
Calliphora vicina
Dilophus nigrostigma
Apis mellifera
Leioproctus spp.
Melangyna novaezealandiae
Light sun
Eristalis tenax
Humidity
Lasioglossum spp.
Wind max
Temperature
Date
−0.10
−0.05
0.00
0.05
0.10
NMDS1

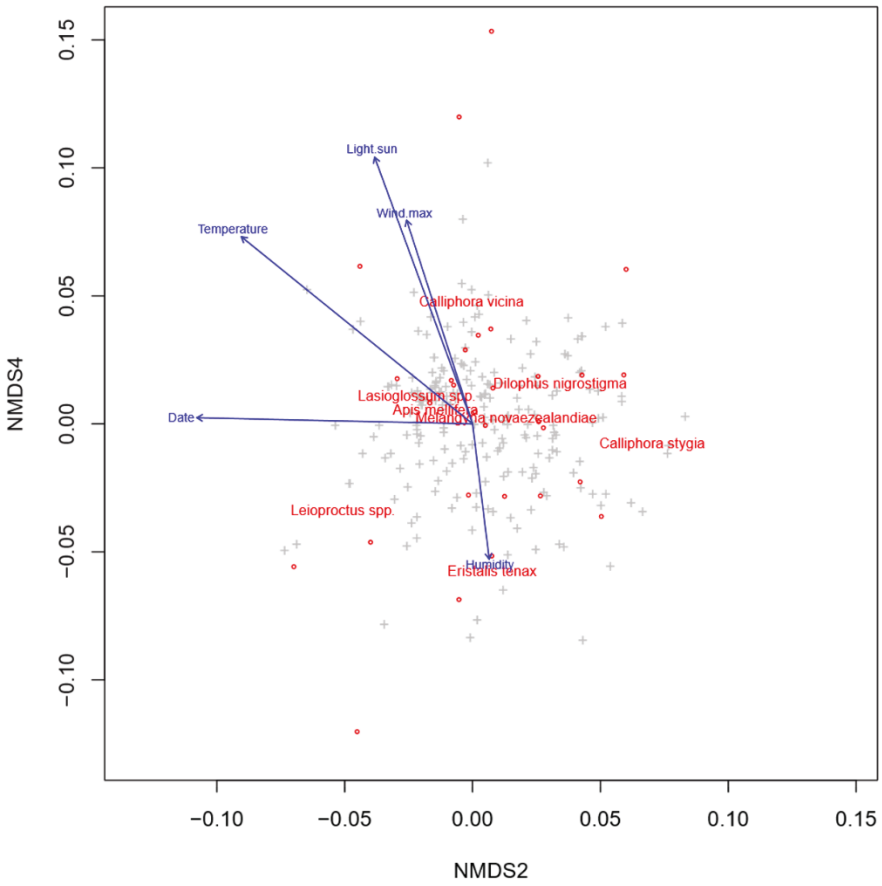
c)


NMDS4
NMDS1
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.10
−0.05
0.00
0.05
0.10
0.15

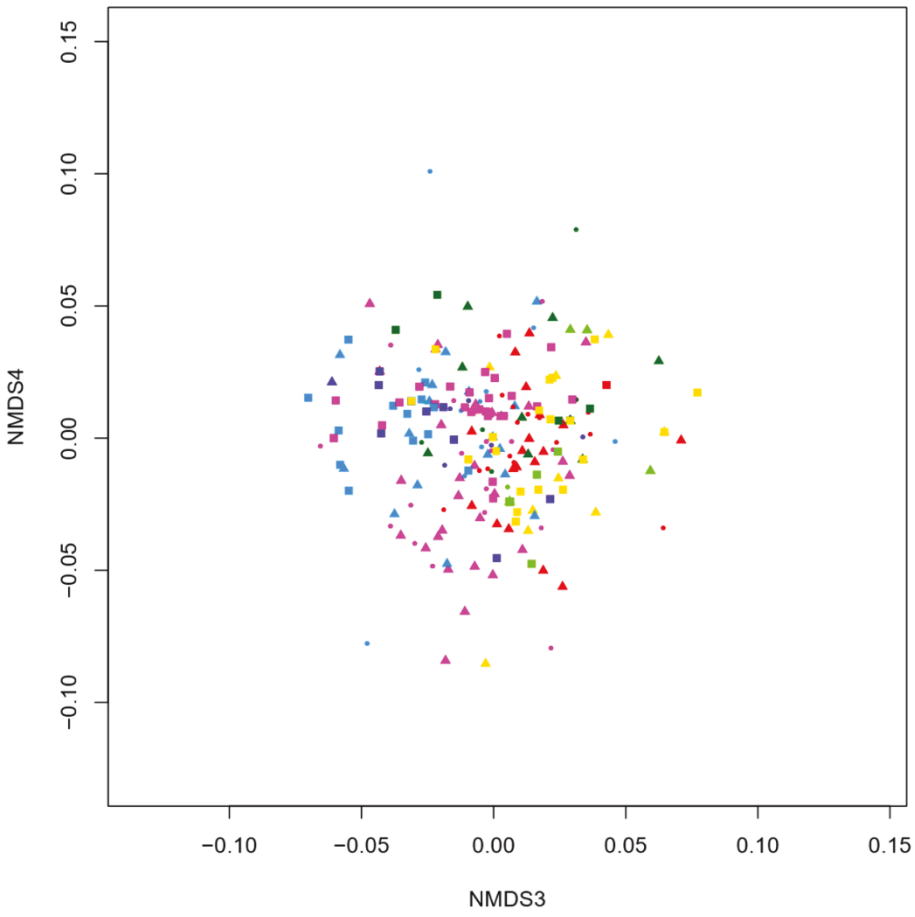

NMDS4
NMDS1
Light.sun
Wind.max
Temperature
Calliphora vicina
Dilophus nigrostigma
Lasioglossum spp.
Apis mellifera
Date
Melangyna novaezealandiae
Calliphora stygia
Humidity
Leioproctus spp.
Eristalis tenax
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.10
−0.05
0.00
0.05
0.10
0.15

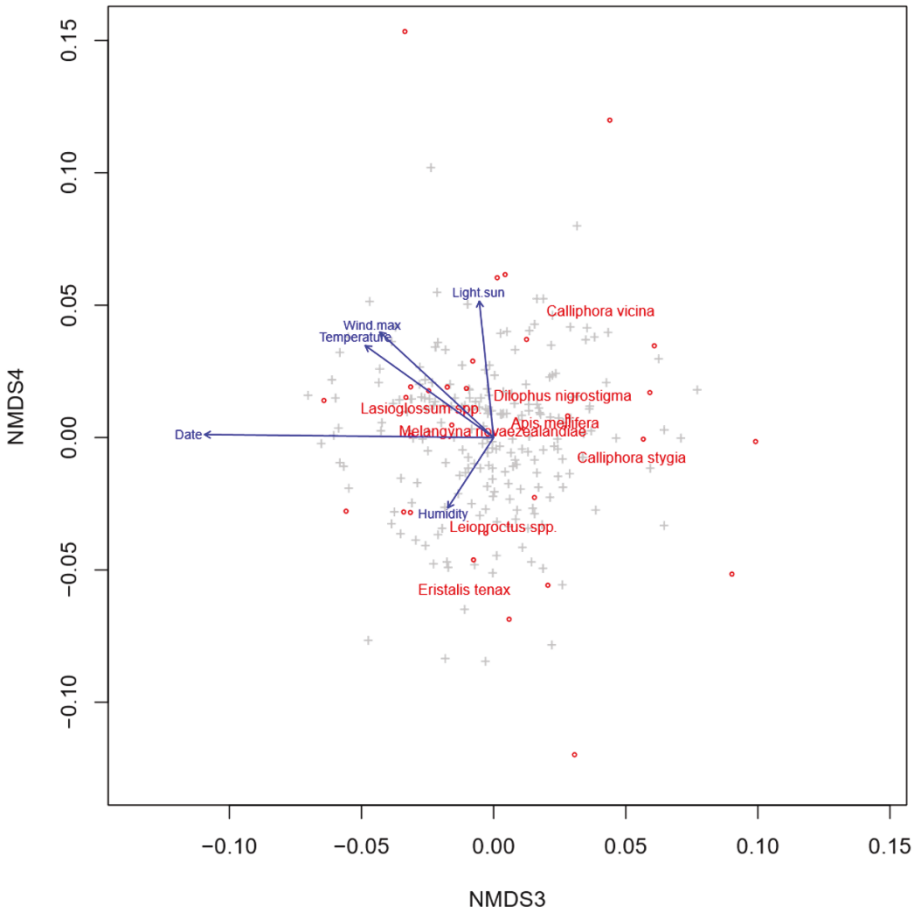
d)


NMDS4
NMDS2
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.10
−0.05
0.00
0.05
0.10
0.15


NMDS4
NMDS2
Light.sun
Wind.max
Temperature
Calliphora vicina
Dilophus nigrostigma
Lasioglossum spp.
Apis mellifera
Melangyna novaezealandiae
Date
Calliphora stygia
Leioproctus spp.
Humidity
Eristalis tenax
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.10
−0.05
0.00
0.05
0.10
0.15

e)


NMDS4
NMDS3
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.10
−0.05
0.00
0.05
0.10
0.15


NMDS4
NMDS3
Light.sun
Wind.max
Temperature
Date
Humidity
Calliphora vicina
Dilophus nigrostigma
Apis mellifera
Calliphora stygia
Lasioglossum spp.
Melangyna novaezealandiae
Leiopodus spp.
Eristalis tenax
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.10
−0.05
0.00
0.05
0.10
0.15

When a priori contrasts were used to examine combinations of plant species, significance differences in insect species composition where found between flowers of *Veronica salicifolia* and *Cordyline australis*, *Carmichalia australis/Phormium tenax* and the remainders of plant species, *Ozothamnus leptophyllus* and the remainder, and *Veronica salicifolia*/*Cordyline australis* and *Kunzea serotina*/*Leptospermum scoparium* (Table 4-18) The insect species most responsible for driving these differences among plants can be seen in the results of the Simper analysis (A. 2).

Table 4-18 Adonis analysis of the effects of environmental variables on the species composition of insect flower visitors in two minute surveys. See the Methods for descriptions of how each weather variable was measured.

	Df	SumsofSqs	MeanSqs	F Model	R2
Date	1	0.021	0.055	20.273	0.001
plant_sciname	1	0.044	0.112	6.937	0.001
Temperature	1	0.008	0.020	7.4773	0.001
Humidity	1	0.002	0.006	2.3755	0.021
Wind.max	1	0.006	0.014	5.3210	0.001
Light.sun	1	0.001	0.002	0.8658	0.565
property	2	0.008	0.020	3.6748	0.001
Date:plant_sciname	6	0.006	0.017	1.0252	0.456
Date:Temperature	1	0.003	0.008	3.0147	0.003
Date:Humidity	1	0.004	0.010	3.6490	0.003
Date:Wind.max	1	0.005	0.014	5.1729	0.001
Date:Light.sun	1	0.003	0.007	2.5190	0.015
Date:property	2	0.009	0.023	4.3226	0.001
plant_sciname:Temperature	6	0.010	0.025	1.5552	0.049
plant_sciname:Humidity	6	0.011	0.029	1.8247	0.007
plant_sciname:Wind.max	6	0.014	0.036	2.2476	0.003
plant_sciname:Light.sun	6	0.011	0.027	1.7017	0.030
plant_sciname:property	11	0.012	0.030	0.9995	0.493
plantcontrasts_CarmVSPho	1	0.000	0.000	0.418	0.001
plantcontrasts_CarmPhoVSrest	1	0.006	0.006	5.387	0.014
plantcontrasts_OzoVSremainder	1	0.022	0.022	21.155	0.057
plantcontrasts_HebCorVSKunLep	1	0.008	0.008	7.602	0.020
plantcontrasts_KunVSLep	1	0.001	0.001	0.862	0.002
plantcontrasts_HebVSCor	1	0.007	0.006	6.201	0.017
plant_sciname:Temperature	6	0.010	0.025	1.5552	0.049
plant_sciname:Humidity	6	0.011	0.029	1.8247	0.007
plant_sciname:Wind.max	6	0.014	0.036	2.2476	0.003
plant_sciname:Light.sun	6	0.011	0.027	1.7017	0.030

	Df	SumsofSqs	MeanSqs	F Model	R2
Temperature:Humidity	1	0.001	0.003	1.0534	0.412
Temperature:Wind.max	1	0.001	0.004	1.3703	0.231
Humidity:Light.sun	1	0.001	0.002	0.8793	0.550
Humidity:property	2	0.005	0.013	2.4030	0.006
Wind.max:Light.sun	1	0.002	0.006	2.0447	0.048
Wind.max:property	2	0.002	0.006	1.0600	0.398
Light.sun:property	2	0.005	0.013	2.4037	0.015
Residual	277	0.185	0.476		
Total	251	0.389	1.000		

4.4 Discussion

The results show that the flower visiting species composition changes as different plant species begin and complete flowering. Fewer insect taxa are present during early-mid spring, while the largest number are present from mid Spring through mid summer (when surveys were discontinued). This part of the study also indicated that the flower visitor abundances in native plantings is, not surprisingly, changing with the flowering season during the summer period. Moreover, most of the native and exotic flower visitors were active in abundance when the early flowering native plants were in peak bloom that was from early November until mid-December. Therefore, the plantings demonstrate a favourable outcome for encouraging insect populations at crop field margins prior to several key insect pollinated crops grown on these farms reaching full bloom. Onion, carrot, radish, in particular, typically flower from late December to mid-January. At this time there was a dip in flower visitor abundances and taxa richness in the native plantings (at the end of December (Fig.4-2)). A likely explanation for this reduction in insect abundance is that there was also lower abundance of flowers in the three plant species available as food resource at the time. Therefore, insects may have been seeking floral resources elsewhere on the farms.

For all insect species the day of the observation had a significant effect on their abundance in the plantings. The seasonal pattern of flowering phenology of plants and their attraction to insect explains the strength of this variable. Permutational Multivariate Analysis of Variance also found that relative abundances of insect flower visitors not only changed depending on the variables of date and plant species, but also interactions between temperature and light, or temperature and humidity etc. For all species the day of the observation had a significant effect on their abundance in the

plantings. The seasonal pattern of flowering phenology of plants and their attraction to insect explains the strength of this variable.

The abundance of native and exotic insect flower visitors not only changed depending on the variables of date and plant species, but also on interactions between temperature, light, wind, and humidity. Interestingly, different species responded differently to date and the weather variables, suggesting that this diverse assemblage will provide more consistent pollination service across the season and across varying weather conditions than any of the species alone. Some insect species showed complimentary characteristics when reacting to weather influence, e.g. *Apis mellifera* abundance count was positively affected by humidity, where as *Calliphora stygia* reacted the opposite to these two variables. Interestingly *Lasioglossum* sp and *Melangyna novaezealandiae* appeared to compliment one another, with *Lasioglossum* sp. reacting positively to temperature drop but *M. novaezealandiae* abundances increasing with a rise of temperature. It could be that *Lasioglossum* sp. is more reactive to higher temperature reducing activity, whereas *M. novaezealandiae* is not assensitive to temperature changes.

The study did not find evidence of distinct flower visitor assemblages for each plant species. For those insects identified to species level, presence was across multiple plant species, therefore these plantings follow the theory that in New Zealand native plants rely on a higher proportion of unspecialised and imprecise insect pollinators (Lloyd, 1985; Newstrom & Robertson, 2005).

All variables assessed in Results 4.5 showed to some degree a significant effect on the abundance of some of the insects. Most often of importance were the plant species, the day of survey within the season, and wind variables which affected most insect species abundance. Surprisingly, in this study the light intensity and humidity were not as important as expected , as these factors have been shown to influence different species of crop flower visitors in New Zealand (Howlett, 2013).

Arroyo et al. (1982a) mention in their study that insects are less active when temperatures are exceptionally high or cool and windy. The survey observations confirmed this with all of taxa with exception of *Apis mellifera, Leioproctus* spp. and *Dilophus nigrostigma* abundances influenced by temperature and all except *Apis mellifera* influenced by wind. *A. mellifera* activity is known to be significantly dependent on temperature, solar radiation, and wind speed. My study was conducted with surveys during a very mild summer (average temperatures of 18.8^{o}C) (NIWA, 2017) with all observations conducted above 12^{o}C and with wind of less than 15km^{-hr}, so perhaps the temperature was always suitable for *Apis mellifera*, despite other flower visitors being influences by these variables.

The second most abundant taxa, *Lasioglossum* sp. was influenced by all environmental variables except the light strength. *Lasioglossum* sp. breed at ground level and their flight activity tends to be close to the ground, although not as close as *Leiproctus* spp. (F. Schmidlin observation). Light intensity might not affect these insects' movement. It is possible that *Lasioglossum* sp. is able to forage in overcast or low light conditions if other variables are ideal. *Lasioglossum* sp. forage on a wide range of flowering plant species (exotic and native) and they have a long nesting period (Donovan, 2007). These are all welcomed characteristics in an arable crop growing environment.

To summarise, the studied young native plantings among the arable monocultural landscape provides an abundance of diverse beneficial pollinating insect early in the growing season. With our results it far more supports the argument that the plant's time of flowering, and different weather variables dictate the abundance and composition of pollinators in New Zealand. With more knowledge of the habitat requirements and flower use behaviours of these insects, it seems likely that this insect community, if supported by a steady supply of flowers through the growing season, can provide a stable secondary source of pollination in these agricultural systems, complementing commercial *Apis mellifera* hives.

Chapter 5

Dispersion of flower visitors into the field

5.1 Introduction

Understanding the movement patterns of wild pollinating insect species from native vegetation and other landscape features on farms is important for evaluating the temporal and spatial provisioning of on farm pollination services (Jauker et al., 2009). Despite limited knowledge on how and where wild bee and non-bee pollinators move on arable farms, previous research has found that pollen transport distances among generalist pollinators in human-modified landscapes can be variable (Rader et al., 2011). As the flight radius of an individual insect is limited by internal (e.g. physiology, morphology) or external factors (e.g. landscape barriers), some pollinating insects readily move further than others (Zurbuchen et al., 2010). Understanding the movement patterns between plant species on farms has important implications for crop pollination, because of its influence on the diversity of crop pollinator assemblages along with issues of unwanted gene flow between crops and related weeds that could result in unwanted genetic contamination of seed crops (Mesa et al., 2013; Rader et al., 2011).

The understanding of insect pollinator flight distances can help with managing the presence and distribution of their communities within intensified agricultural landscapes. This includes the knowledge of optimum distances between breeding spots and food resources of pollinator species. However the differences between species in the requirement for nesting places, needs of the larvae and floral resources for adult insects, are particularly difficult to analyse (Cunningham et al., 2013). In contrast to bees, which are spatially constricted with their nesting areas, insects from the Diptera family, such as hover flies, select a suitable microhabitat for their oviposition and do not have nests (Jauker et al., 2009).

Despite these difficulties in assessing dispersal distances from nesting sites, or general flight distances of insect species, it is commonly accepted that species' diversity and abundance are negatively affected by distance to natural habitats (Bailey et al., 2014; Geslin et al., 2016; Kremen et al., 2002; Ricketts et al., 2008; Zurbuchen et al., 2010). However, two recent studies from Germany (Jauker et al., 2009) and New Zealand (Stavert et al., 2018) found some generalist exotic species such as the drone fly (*Eristalis tenax*) have abundances that can increase while native insects diversity and abundance decreases with an intensification of agriculture practices. In contrast, Hartley (2018) unexpectedly showed in her recent study conducted in Taranaki, New Zealand, that the abundance

of native bees increased with agriculture intensification. To our knowledge, there are no studies that have been conducted to determine the dispersal of invertebrate flower visitors from native plants (see Chapter 4) into adjacent crop fields in New Zealand.

Insect species would be expected to vary in their frequency and dispersal distance from these native habitats, depending on their life cycles, behaviour and the attractiveness of nearby crops outside of native plantings. It is known that pollinators readily move to and from flowering crop fields (Mesa et al., 2013) and several species of flies and bees move at least 400 m into the surrounding landscape (Rader et al., 2011). However, even with increased global interest in flight movements of pollinators (Pasquaretta et al., 2017; Zurbuchen et al., 2010), methods to determine dispersal distance from native habitats are varied and results can be contradictory, often overestimating or underestimating flight distances (Bailey et al., 2014; Greenleaf et al., 2007; Lentini et al., 2012; Zurbuchen et al., 2010).

5.1.1 Objectives

This part of the study investigated the spatial and temporal flight movements of flower visitors in vicinity of native plantings within an arable landscape.

The following questions were addressed:

1) What insect species will get trapped at set distances (0 to 250 m) from semi-natural habitat?

2) Do some insects carry the pollen of native trees from the plantings, and if so, what distance to the plantings are they captured?

5.2 Study site

The data collection was conducted on three arable farms within 50 km of Rakaia, Canterbury. Native biodiverse plantings were established in October 2013 on all three farms.

Please refer to Chapter 2 for more details on local arable history, study sites and plantings.

5.3 Principal trapping method

Various methods have been employed to assess insect foraging distances, most of these have focussed on the movement patterns of wild bees (Beil et al., 2008; Bennett et al., 2018; Greenleaf et al., 2007; Zurbuchen et al., 2010) with very few examples assessing non-bee pollinators (Jauker et al., 2009; Macdonald et al., 2018 in press; Stavert et al., 2018). Methods used include harmonic radar for larger insects such as bumblebees and butterflies (Cant et al., 2005; Osborne et al., 1999) , the displacement of bees from their nest (Gathmann & Tscharntke, 2002) or feeder training (Beil et al., 2008).

These methods work particularly well for bee species (Zurbuchen et al., 2010). To include a data collection of a wider diversity of insects, other experimental methods work successfully using trap stations such as flight interception-, pan-, sticky- and malaise traps or sweep nets (Bailey et al., 2014; Howlett, Walker, Newstrom-Lloyd, et al., 2009; Kearns, 1993) at specific distances from the pollen sources. Insects are then assessed for pollen identity to verify their origin (Mesa et al., 2013; Rader et al., 2011). The passive method of insect trapping by sticky traps is suitable for assessing the identity of pollen from the bodies of each insect specimen separately.

Methods used in previous studies which left the insects wet or may result in pollen mixing, were dismissed as candidate methods for this study. In New Zealand, a recent study showed that sticky traps and the colour yellow were the most effective way of trapping Hymenoptera species in an apple orchard (Larsen et al., 2014) and this colour has been previously used to explore the movement of flower visitors in New Zealand (Mesa et al., 2013; Rader et al., 2011). For two common native hoverfly species in New Zealand, *Melanostoma fasciatum* and *Melangyna novaezealandiae*, more individuals were caught in plain yellow traps than in yellow/green traps (Laubertie et al., 2006). This was supported by other studies assessing other Syrphid genera (Bowie et al., 1999; Macleod, 1999) many bee species (Leong & Thorp, 1999) and insects from the family Diptera (Proctor, 1996). Therefore the choice for this study was to use the simple passive method of yellow sticky traps set on visual large yellow coreflute boards (90 cm x 90 cm) at specific distances to the native habitats.

This process allowed sampling of a number of insects and distances to habitat, over a short sampling interval. The dry trapping method permited the collection of individual insects that had adhered to the board so that pollen loads could be sampled. These samples were also amenable to non-hydrated preservation of the pollen.

5.3.1 Trapping in the field

On each of the study farm sites, ten yellow corflute-boards, each with two sticky sheets attached, and one fixed below board, were set at 0 m, 25 m, 50 m, 150 m, and 250 m distance in an easterly and westerly orientation away from the plantings (see Chapter 2). The two trapping days were set in December in January (expected peak of flowering times).

Each of the yellow boards measured 90 cm x 90 cm, were vertically placed facing the plantings supported by two waratahs (Fig. 5.1, 5.2, 5.3) Two yellow sticky sheets (40 cm x 25 cm BugScan^{R}) were pinned to corflute in an upright direction in the middle of the coreflute board with a third sticky sheet pegged horizontally, 30cm above ground into the grass (Fig. 5.4). Each trapping period lasted for 48 hrs, which resulted in 10 boards exposed to a total of 96 hrs to flying insects. These trapping days were conducted in warm (day time forecast > 18^{o}C) and with low wind forecast to reduce wind-blown insects and dust blown onto the sticky sheets. The sheets were then collected by covering them up with plastic wrap and stored in the freezer at -18^{o}C.

Figure 5-1 Coreflute lure with sticky sheets traps set at 0 to 250m distance, direction West Farm2

Figure 5-2 Farm 1 Set traps in sheep paddock, towards West, 0m not visible, close to natives

Figure 5-3 Farm 3, Traps set in grazing paddock, West, with native plantings in background

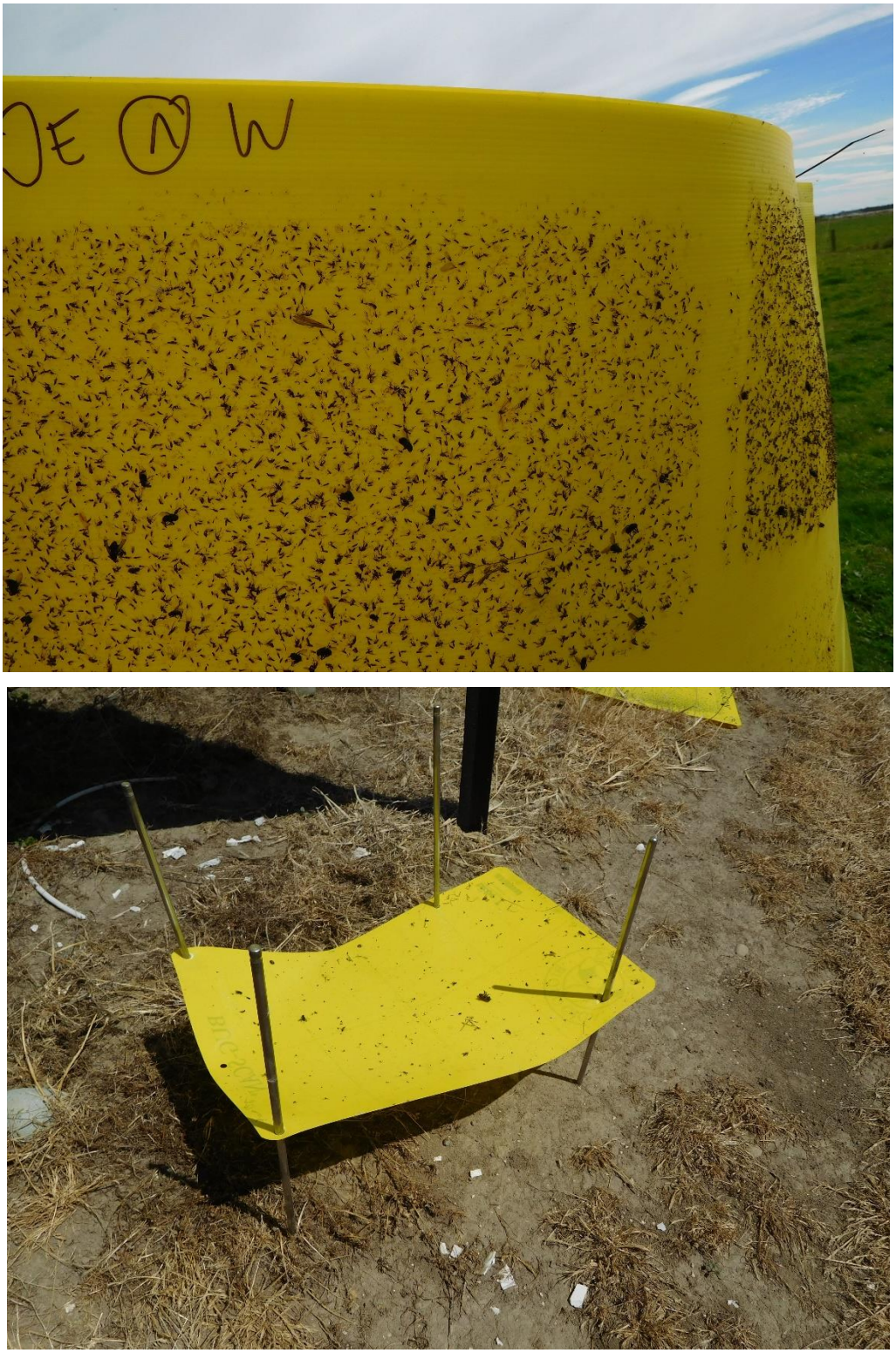


Figure 5-4 Traps were set up in horizontal and vertical way.

5.3.2 Insect identification

Unknown flower visitors were identified with the help of Sam Read (Plant and Food Research) and New Zealand native bee specialist Barry Donovan (*Donovan* Scientific Insect Research). The most abundant taxa were identified to the highest level of taxonomic resolution possible, largely to species (e.g. *Melangyna novaezelandiae)* or genus (e.g. *Leioproctus* spp) and less often to higher taxa (e.g. Family Tachinidae).

Insects smaller than < 3mm and many slightly larger insects of the family Ephydridae (shore flies) were not recorded.

5.3.3 Pollen collection from plants

Pollen samples were collected from each plant species on each farm site as a reference collection to aid with the identification of pollen on insects. Pollen was collected fresh from opening anthers and transferred onto 3 mm^3 Gelatin-Fuchsin cube (Beattie, 1971) and placed on a microscope slide, covered with a glass cover slide and then the Fuchsin gel melted slowly by placing on a sun heated surface under glass. On melting, slides were then allowed to set under low light and temperature conditions, then transferred to the laboratory for storage and assessment.

5.3.4 Pollen collection from insects

I examined the sticky sheets per trap location and chose by eye the ones which had the largest collection of pollinators on them. Two of the three sticky sheets were chosen, very rarely only one if pollinators on sheet exceeded 50 specimens. This was done to ensure a sufficiently large number of pollinators collected from each distance from the plantings, as there was not sufficient time to process all insects. Other insects on the sheets not removed for pollen collection were identified, counted, and discarded.

In the laboratory, different methods were attempted to dislodge the pollen from the insects, i.e. physically rubbing pollen from the legs, abdomen, thorax and head parts; using water, alcohol or Alexander's stain (Kearns, 1993) to wash the specimens. None of these methods successfully dislodged the pollen, most likely because of the strong glue from the sticky traps which made the pollen grains adhere to the insect. Therefore the insects were removed from the frozen sticky sheets and mounted on slides as whole insects, covered up with Fuchsin gel (Radford et al., 1974) and cover slides, then placed in laboratory drying oven at 50^{o}C for 20 min to melt the gel.

5.3.5 Pollen identification

The pollen grains on the insects were examined under 100 power, up to 400 power magnification lens of an upright microscope (Nikon Eclipse Ni-U) with a mounted camera (Nikon E995). The pollen grain structures were compared with the collected pollen library and the reference pollen Atlas of Moar (1994).

5.3.6 Data Maintenance

The goal was to examine whether the numbers of individual insects varied among species and with distance from the native habitat edge. A mixed effects model was used, in the lme4 R package, with insect taxa and distance from the habitat (1= 0m, 2= 25m, 3= 50m, 4= 150m, 5= 250m) as fixed factors and farms as a random effect.

A further focus of the study was to identify pollen grains collected on insects at varied distances to the semi-natural habitat. Formal statistical analyses were not considered necessary here due to the lack of reliably identified pollen grains other than *Kunzea serotina* pollen on seven insect specimens.

5.4 Results

5.4.1 Flower visitor species distances from semi-natural habitats

Insect species diversity

Insect dispersal patterns are derived from data of the trapping experiment. They provide qualitative information and serve as a broad record of insect dispersal only.

In total, 1010 insects were collected and identified across all sticky traps and locations. On some traps, many hundreds of small insects were trapped; a large proportion of them from the dipteran family Ephydridae. These flies are known flower visitors but not proven effective pollinators (Howlett, Walker, McCallum, et al., 2009; Walker et al., 2011). Although some are larger than 3mm in length, most may not carry pollen sufficiently to pollinate (Rader et al., 2011) so I have therefore excluded them from a further analysis. Identification was concentrated on insects known or seen as pollinators in crops or native plantings (Howlett et al., 2017; Howlett et al., 2011).

Of the 1010 pollinating insects, I identified 15 taxa to species level, one to genus and three to family. These insects were present on 29 traps across the three farm sites and included four species of bees (three natives) and eight species of flies (three natives). The most abundant pollinating insect taxa

found on all boards across the three farms were combined species from the family of the Muscidae (18%), *Lasioglossum* sp (18%) followed by *M. novaezelandiae* (15.8%) combined species within the Calliphoridae (14.5%) and native hover fly *Melanostoma fasciatum* (5%). The remaining insect taxa represented approximately 30% of all other insects. It is interesting that the three native species compete in abundance with a whole group of insect species in the family groups Muscidae and Calliphoridae as this differs from a study by (Larsen et al., 2014) who caught mostly honey bees on sticky traps in an apple orchard in New Zealand. The sticky traps captured just two single honey bee specimens in total. This was surprising, as a line of traps on farm 1, were just 15m away from an apiary site. One explanation for this might be the quality of the glue on the sticky boards which might have not been strong enough to trap larger, heavier insects, such as honey bees. Alternatively, the yellow lure of the traps may not have been sufficiently attractive to the honey bees, pParticularly if the traps were competing with flowers providing nectar or pollen (not in sight of the researcher's eye) causing the bees to bypass traps within their flight path.

Pollen grains on insects

The species found carrying the largest variety of pollen grains were *Melangyna novaezealandiae, Eristalis tenax*, *Lasioglossum sp* and *Calliphora stygia*. All of them carried pollen grains represented by at least seven different pollen plant species, either stuck to body or consumed (visible under the microscope for the *Melangyna novaezealandiae*). All of the insect species found in our traps had at least two different pollen species collected on their body parts.

Table 5-1 Summary of captured insects on sticky traps in field

Number of insects analysed for pollen existence on their body	748
Number of insects with pollen	700
Number of insects with native plant pollen of *Kunzea serotina*	7
Number of insects with 1 pollen species only	196
Number of insects with 2 pollen species	118
Number of insects with 3 or more different pollen on one insect	262
Insects too damaged to be able to work on	62

Insects captured at distances from native plantings

Most insect species or families were trapped across the different distances the traps were placed - 0m to 250m. However, there was evidence that distance from the native plantings influenced the abundance of the dipteran families Musicdae (P=0.04) and Calliphoridae (P=0.01), as well as the calliphorid species *Calliphora vicina* (P= 0.03), Muscidae were found to increase in abundance at further distance from the plantings whereas Calliphoridae were more often caught at the edge of the plantings. This pattern was consistent across all three assessed farms. Two of the most commonly caught native insects (*M. novaezealandiae, Lasioglossum* sp.) were spread-out over all distances. (Table 5-2)

Table 5-2 For the two most commonly caught native insects, this table shows the distribution of th specimens in regards of the trapping distance to the semi-natural habitat.

Insect species	Insects at 0m from habitat	Insects at 25m from habitat	Insects at 50m from habitat	Insects at 150m from habitat	Insects at 250m from habitat
Melangyna novaezealandiae	51	28	29	31	33
Lasioglossum sp.	40	37	36	23	48

5.4.2 Native plant pollen on insects and the evidence of insects' dispersal from native plantings into field

748 of 1010 trapped flower visitors were examined for pollen existence on their bodies. Of these 748 insects a total of 48 specimens had no pollen found on them.

Only the plant species *Kunzea serotina* pollen grains could reliably be identified as a pollen from the family Myrtaceae and most probably belonged to *Kunzea serotina* in the native plantings given the lack of other nearby Myrtaceae. For all other pollen grains, a definite identification could not be provided, due to close similarities in pollen shape and size to other pollen species within each of the families. For example, the members of the family of Asteraceae, which included *Ozothamnus* sp., consist of plant species such as weeds (Dandelion, *Taraxacum officinale*) which were likely grown anywhere in the vicinity of the study sites (roadsides etc.). Therefore, I was not able to distinguish pollen grains with certainty using the chosen method of pollen identification for this part of the study. (An attempt at identifying these plants with extracted DNA was unsuccessful.)

For the very few (seven) *Kunzea serotina* pollen grains found on insects, the majority (four) were found on *Melangyna novaezealandia,* two were found on *Lasioglossum* sp, and each one on *Odontomyia* spp. and on an insect of the Muscidae family.

Two insect specimens with *Kunzea* sp pollen attached were found in 250 m distance (*M. novaezealandia* and *Odontomyia* sp), two at 150 m (*Lasioglossum* sp and *M. novaezealandia*) one

each at 50 m (*Lasioglossum* sp), 25 m (*M. novaezealandia*) and 0 m (Muscidae) distance from the habitat.

5.5 Discussion

It was hypothesised that in a highly intensified landscape in Canterbury, insect species' diversity and abundance would be negatively affected by distance to native plantings. This was based on studies in a European and North American environment and is commonly accepted (Bailey et al., 2014; Geslin et al., 2016; Kremen et al., 2002; Ricketts et al., 2008; Zurbuchen et al., 2010).

The results of this study did not provide evidence to support this. Most captured pollinator species were evenly spread throughout all sticky traps This may indicate that a relatively diverse insect community was evenly distributed across the landscape irrespective of the native plantations – at least up to 250 m radius around the native plantings. Although the study found evidence of insects collecting native pollen from the pollen source up to 250 m away, this would need a larger additional study or alternatively with different pollen identification methods, to confirm whether more insects were moving between native resources and crop fields. Instead of microscopy pollen ID the use of DNA metabarcoding could potentially allow faster and finer-scale taxonomic resolution of pollen (Bell et al., 2017).The plantings, as described in Chapter 3, provide a substantial diversity and abundance of insect flower visitors and known crop pollinators within. The insect observation time (around 40 hrs) in flowering native plantings and the collecting time of flying insects by traps (48 hrs exposure) in the field were comparable. The result of double as many insect species in native plantings compared to the field on traps (29 compared with 15 species) lies in line with several publications(Kennedy et al., 2013; M' Gonigle et al., 2015; Morandin & Kremen, 2013): vegetative diversity locally boosts pollinator species richness and abundance. However, this is comparing two very different collecting methods and so this conclusion is tentative and needs further testing.

Although Stavert et al. (2018) and Jauker et al. (2009) describe the increase of pollination service by Syrphidae in response to increased intensity of land-use (mainly the exotic *Eristalis tenax* in brassica crop in New Zealand (Stavert et al., 2017), this study presented results with two of the most abundant species encountered as native Syrphidae species.

Unsurprisingly the native Syrphidae flies were spread throughout the landscape. Reproduction of these species is possibly in arable fields with no need for adults to feed offspring actively; the driver of the abundance of this group of pollinators is therefore not the food resource for adults, but associated with the larval requirements (Jauker et al., 2009).

The native *Lasioglossum sordidum* was captured in relatively even numbers irrespective of distance from the native plantations. Hartley (2018) stated in her study that abundance of certain native bees (*Lasioglossum sordidum* included) was positively linked to increased agriculture and exotic vegetation. (We identified all the chosen samples of *Lasioglossum* sp. as *L. sordidum,* but due to time constraint weren't able to identify all the *Lasioglossum* specimens to species). The advantageous characteristic of these native bees is their ability for finding nesting sites in bare soil (B.J. Donovan, 2007), i.e. ploughed edge of field, wheel track of irrigators (personal observation). These native bees have been recorded to feed on both introduced and native flowering plants (B.J. Donovan, 2007) and exotic plants and this flexibility may allow it to remain common within intensively farmed landscapes (Hartley, 2018).

The catches in the traps from 0 m to 250 m of the Calliphoridae family significantly decreased with distance to the native plantings on all three farms. This may be explicable by the fact that these flies need carrion and decomposing leave matter to breed (Dear, 1985). Besides only one sheep paddock (providing dung) on farm 3, all other setup of traps were in fields with ryegrass, clover, oats and along a stony access road; these are conditions with not much decomposing matter.

The appearance of Muscidae flies away from the plantings requires further investigation. It would help to additionally identify the Muscidae flies to species level, since some of their species are predaceous or saprophagous in decaying organic matter, some breed in water (highly polluted is? possible) while most adults feed on nectar although some species' are entirely predaceous with larvae feed on other fly larvae and worms and adults on blood and sweat (Ivković & Pont, 2015). Species identification might help to explain their status in distance to native plantings in our study.

Of particular interest is the evidence of Kunzea pollen grains on insects caught out in the field. *M. novaeazelandiae*, *Lasioglossum* sp., *Odontomyia* spp.and an unidentified muscid were found carrying the *Kunzea serotina* pollen. All but the muscid were species recognised as crop pollinators of onion, carrots and pak choi (Howlett et al., 2011; Rader et al., 2009). This finding demonstrates that insect will move into the surrounding landscape from the native plantings.

In light of the very small sample size, it is not possible to conclude with confidence whether certain species are more likely to move into surround crops or pasture than others, nor how far they may potentially travel in a single flight. However, insects with pollen were trapped, up to 250 m away from plantings, and suggest that *M. novaezelandiae* and *Lasioglossum* sp. visit native planting and could potentially fly distances of several hundred metres into the surrounding landscape. This axiom proposes that field margin habitats provide an adequate refuge for insects while the fields are ploughed, sprayed, mowed, grazed (Howlett et al., 2013; Morandin & Kremen, 2013). This refuge also provides food resources while there is no crop in bloom. Native plantings within crop fields or

along field margins are landscape features which are likely to enhance crop pollinators and their ecosystem service in an arable landscape (Morandin & Kremen, 2013).

The composition of the trapped pollinating insects are fairly representative of New Zealand's depauperate pollination fauna represented by a high proportion of generalist insect pollinators (Pattemore, 2013). As all the species and genera caught contained pollen from at least two different plant species, there were no apparent specialist pollinators revealed. Generalist pollinators, and predators for that matter, are more likely to survive in a highly disturbed environment (mechanical soil disturbance, irrigation, resource variety limitation etc.), whereas floral specialists have a limited resources and may struggle to survive in a monocultural landscape (Stavert et al., 2017).

Support of crop pollinator communities, whether specialists or generalist foraging species, around or within crop fields can optimise seed yield (Lentini et al., 2012). With a growing hybrid seed crop industry in southern Australia and New Zealand, New Zealand grows now over 400 mostly hybrid vegetable seed crops (Gaffney et al., 2011; Millner & Roskruge, 2013) there is a need for not only a good understanding of the pollinators' flower preferences, but also of the pollen transport distances of the different insect species and behavioural interactions between them. Further research is required to fully understand the economic value of pollinator communities associated with native plantings on farms to ensure growers can make decisions on whether it is worth investing in establishing similar semi-natural habitats.

Chapter 6

Recommendation

6.1 Implications for farm management

It is clear from my results that established native plantings at field margins are used by a diversity of flower visiting insects, including many known crop pollinators (Chapter 3,4). These diverse pollinator communities are not only retained within the native vegetation but move into the surrounding agro-ecosystem to at least 250m (Chapter 5). The fact that some of the insects moved between the plantings and the field gives an indication that crops adjacent to plantings are likely to be visited and receive pollination by these pollinators.

The existence of diverse flower visitors (at least 37 species), on only eight different plant species, is an encouragement to farm managers that even small or narrow plantings (<1 ha and as narrow as 3m) can support beneficial insects, even in a short amount of time since planting as this study was conducted just four years after their establishment. The majority of these flower visitors (honey bees, native large and small hover flies, native *Lasioglossum* and *Leioproctus* bees, and many other Diptera) have been recognised as crop pollinators of onion, pak choi, carrots, white clover, and radish (Howlett et al., 2011; Rader et al., 2009). Moreover, very few herbivorous insects were observed on open flowers within the native plantings, although my surveys were only done in the daytime and some herbivorous Lepidoptera may visit these flowers at night. It is notable that insects known to cause damage in both agricultural and horticultural crops such as the black soldier fly (*Eumerus figurans*)(Ricarte et al., 2017) and the common cabbage white butterfly (*Pieris rapae*) were only observed in very low numbers during the summer 2017/18. Further research will be needed into how to manipulate populations of beneficial crop pollinators without increasing pest species, particularly in cases of the brown blow fly (*Calliphora stygia*), and the European green blow fly (*Lucilia sericata*), which contribute to fly-strike (*cutaneous myiasis*) in sheep.

Although not the focus of this study, it is likely that the creation of on farm habitat diversity such as through the native plantings could also support bee nesting-sites through the provision of undisturbed soil. Shaded water sources are expected to suit the development of some pollinating fly larvae (e.g. *Odontomyia* spp.), and the presence of leaf litter is expected to support larval stages of many pollinators (e.g. Bibionid fly larvae, (D' Arcy-Burt & Blackshaw, 1991)).

Additional management strategies alongside native plantings may also help maintain particular pollinators. For example, providing bare soil strips along fence lines and within crop fields (such as along irrigation wheel tracks) could further encourage native bee populations within the fields. This

farming practice would provide more nest-sites for bees such as *Lasioglossum* species (Hart, 2007)) and I often found nesting *Lasioglossum bees* in bare ground along herbicided fence lines. Furthermore, a very careful insecticide spray regime that avoids the native plantings would help to sustain and grow a diverse insect community. Stavert et al. (2018) emphasised that exotic pollinator insects can maintain sufficient pollination services away from habitat refuges in New Zealand. However, they also warned not to rely on just a few native and exotic pollinator species.

In summary, a combination of careful farm management strategies including planting natives, providing nest-sites for pollinating insects and careful insecticide spray management may be required to ensure the consistent presence of diverse pollinators on farms. New Zealand's agro-ecosystems face continued and significant change through land use intensification and climate change. Building pollinator diversity can ensure that crop pollination is maintained in these changing environments by supporting a mix of species that offer complimentary pollination services under variable weather conditions and across an array of mass flower crops.

6.2 Future research recommendations

The research conducted in this thesis has gathered essential knowledge on the relationship between native plant species commonly used in restoration plantings and insect flower visitors that are known to contribute to crop pollination. Studies into assessing how future plantings benefit agro-ecosystems such as through pollination services will be needed to maximise profit on farm land use. With this study I have demonstrated that such plantings support a wide variety of known crop pollinators on arable farms. However, there is much research required to fully understand the economic impact of such planting on the surrounding agricultural landscape.

Further research is needed to address the following questions:

- How much do native plantings increase the abundance of pollinating insects on a farm scale?
- How does pollinator diversity vary both spatially and temporally between years and as the plantings continue to mature?
- Do pollinating insects move in a predictable way from plantings into surrounding crops, and how far do they typically move?
- How does seasonal weather (and climate change) impact the abundance of each pollinating species?

- How do pesticides, herbicides and irrigation affect the pollinators' numbers in native plantings?

- Do native plantings support beneficial invertebrates by offering more than nectar and pollen, overwintering sites, nesting summer sites?

Long-term studies spanning several years, including winter phenology of insect communities, would provide a greater in-depth perspective of pollinator behaviour and ecology. The pressing question of competition between taxa for limiting resources suggests the need for more in-depth studies. A recent study by (Iwasaki et al., 2018) showed evidence that New Zealand bee communities, exotic versus native, in a native environment have only a limited resource overlap, so there might not be in significant competition, contrary to the expectations from the results of international publications. However, studies indicate that many of our native species occur on exotic crops (Howlett et al., 2015; Howlett, Walker, Newstrom-Lloyd, et al., 2009; McBrydie et al., 2017; Read et al., 2017) and pollinate them (Howlett et al., 2017; Rader et al., 2009) and may compete for these floral resources.

We still lack of key data of specific pollinating taxa for many crops in many regions, although worldwide we have seen an increasing focus in understanding the role of wild pollinating species in crop pollination (Garibaldi et al., 2013; Kleijn et al., 2015; Rader et al., 2016)While floral resource requirements of pollinators in general are more researched than other regulating variables (i.e. nest-sites, pathogens etc.) (Dicks et al., 2015; Steffan-Dewenter et al., 2005), there is still much to learn on the quality of different plant species as food resources and attractiveness of them to the pollinators, e.g. nutrients, calories within nectar and the influence of pollen and floral scent on pollinator attractiveness.

A big gap to fill and great deal of fundamental knowledge is required just to quantify the efficiency and effectiveness of managed and unmanaged pollinators and how the diversity of pollinator groups, pollinator interactions and the functional complementarity between species influence pollinator effectiveness (Canto-Aguilar & Parra-Tabla, 2000; Phillips & Gardiner, 2015; Pisanty et al., 2016). Moreover, there is limited knowledge on the spatial and temporal requirements of bees and non-bee pollinators to determine what pollinator groups are most successful at distinct flowering times for optimal crop yields (Rust et al., 2003; Winsor et al., 2000).

Forthcoming research should also consider careful evaluation of specific crop and crop farm management that also incorporates the non-economic values of biodiverse plantings (e.g. aesthetic, cultural) as well as other poorly quantified ecosystem services (e.g., nutrient interception, carbon

sequstration, reservoirs of predatory invertebrate populations). In the future, a combination of practices in land management and concentration of resources found to support pollinator populations (native plantings, barren strips of land, annual field edge flowers, etc.) might deliver sustainable, but also economically suitable, management practices which may maximize overall pollination services across a larger agroecosystem. Research at farming-community level in different arable growing regions can help to sustain production of diverse crops that nourish humanity.

6.3 Conclusion

The aim of this thesis was to investigate pollinator assemblages associated with native plantings designed to support beneficial insects within the arable landscape of Mid-Canterbury, New Zealand. An assessment of the pollinator assemblages is a necessary step to determine whether the aims of these plantings are being achieved. Specifically, it examined the spatial and temporal variation in abundance and composition of flower visitor species on native plants. The recently established, flowering native plants have shown to be attractive to a wide diversity (37 taxa) of beneficial insects. Of all observed, the majority of flower visitors belonged to eight species, (*Apis mellifera*, *Lasioglossum* sp., *Melangyna novaezelandiae*, *Calliphora stygia, Dilophus nigrostigma*, *Calliphora vicina*, *Leioproctus* spp. and *Eristalis tenax*) with each also being recognised as a crop pollinator. The results of this study indicate that establishing native plantings within highly intensified agricultural landscapes does support a diverse assemblage of pollinating species in the Canterbury Plains over the summer period 2017/18. This study also demonstrated that in neighbouring open fields, a large pollinator population was also present, albeit only half as diverse as the insect community within the plantings. Moreover, I found evidence that some of these insect species originated from the native plantings (*Melangyna novaezealandiae, Lasioglossum* sp., *Odontomyia* spp, on in Muscidae family). Of importance are further studies of these insects' abundance within actual crop fields as influenced by such plantings and their efficiency and effectiveness as pollinators for arable crops. Identification of key pollinating species represented within the pollinator assemblages and assessing their phenological characters including their behavioural traits is essential for understanding their potential benefit to the pollination of crops. Future research needs to further establish a link to agricultural practices, and the implementation and maximisation of overall pollination services in the larger agroecosystem. Moreover, a focus on the economic value of establishing and maintaining such native plantings (costs) with the value of services they support including improved yields, a lower reliance on managed pollinators as well as the non-market benefits that these pollination services may provide such as connection with land by traditional and local peoples, aesthetic values and tourism. It is too early to state with confidence which farm conditions, with which crops, will benefit

economically from including native plantings, and what contribution pollination services can make to that economic benefit. My research suggests that such benefits are plausible and warrant further investigation.

Lasioglossum sp. on unknown plant species Photo Jon Sullivan

Appendix A

A.1 Native Plant List 2013

Table A. 1 Highlighted in this table (green cells) are the eight chosen plant species and their planted numbers. The plant order in table is based on planting plan of landscape designer. Due to growth problems or diseases some of the species have less specimens in 2018. This included *Discaria toumatou* which was removed from most of the analysis in this thesis because there were too few remaining healthy flowering plants to survey.

Native Plant List **Plants planted in 2013 "Better Biodiversity Installation" PFR**					
Farm 1	Plant #	**Farm 2**	Plant #	**Farm 3**	Plant #
Podocarpus totara	**10**	*Cordyline australis*	**102**	*Podocarpus totara*	**50**
Prumnopitys taxifolia	**5**	*Kunzea ericoides*	**169**	*Prumnopitys taxifolia*	**20**
Cordyline australis	**40**	*Sophora microphylla*	**65**	*Cordyline australis*	**150**
Kunzea ericoides	**40**	*Leptospermum scoparium*	**288**	*Kunzea ericoides*	**130**
Leptospermum scoparium	**40**	*Pittosporum eugenioides*	**117**	*Leptospermum scoparium*	**150**
Pittosporum eugenioides	**40**	*Pittopsorum tenuifolium*	**117**	*Pittosporum eugenioides*	**50**
Pittopsorum tenuifolium	**40**	*Carpodetus serratus*	**12**	*Pittopsorum tenuifolium*	**75**
Sophora microphylla	**40**	*Corokia cotoneaster*	**57**	*Sophora microphylla*	**75**

Farm 1	Plant #	**Farm 2**	Plant #	**Farm 3**	Plant #
Corokia cotoneaster	**22**	*Lophomyrtus obcordata*	**57**	*Hoheria angustifolia*	**25**
Hoheria angustifolia	**22**	*Coprosma intertexta*	**12**	*Lophomyrtus obcordata*	**25**
Lophomyrtus obcordata	**22**	*Coprosma lucida*	**12**	*Coprosma intertexta*	**10**
Coprosma intertexta	**10**	*Coprosma robusta*	**12**	*Coprosma lucida*	**10**
Coprosma lucida	**10**	*Griselinia littoralis*	**8**	*Coprosma robusta*	**10**
Coprosma robusta	**10**	*Olearia paniculata*	**8**	*Griselinia littoralis*	**10**
Griselinia littoralis	**10**	*Plagianthus regius*	**8**	*Olearia paniculata*	**10**
Olearia paniculata	**10**	*Pseudopanax crassifolius*	**12**	*Plagianthus regius*	**10**
Plagianthus regius	**10**	*Pseudopanax arboreus*	**1**	*Pseudopanax arboreus*	**10**
Pseudopanax crassifolius	**10**	*Carmichaelia australis*	**126**	*Veronica salicifolia*	**200**
Pseudopanax arboreus	**10**	*Veronica salicifolia*	**269**	*Ozothamnus leptophyllus*	**150**
Myoporum laetum	**10**	*Ozothamnus leptophyllus*	**179**	*Carmichaelia australis*	**80**
Fuchia excorticata	**10**	*Phormium tenax*	**126**	*Phormium tenax*	**120**
Carmichaelia australis	**62**	*Muehlenbeckia astonii*	**37**	*Muehlenbeckia astonii*	**50**
Veronica salicifolia	**45**	*Olearia bullata*	**57**	*Discaria toumatou*	**25**
Ozothamnus leptophyllus	**65**	*Discaria toumatou*	**37**	*Olearia fragrantissima*	**5**

Farm 1	Plant #	**Farm 2**	Plant #	**Farm 3**	Plant #
Phormium tenax	**50**	*Olearia fragrantissima*	**8**	*Coprosma crassifolia*	**5**
Muehlenbeckia astonii	**25**	*Pseudowintera colorata*	**8**	*Coprosma propinqua*	**5**
Discaria toumatou	**30**	*Coprosma crassifolia*	**8**	*Coprosma rubra*	**5**
Olearia fragrantissima	**5**	*Coprosma propinqua*	**8**	*Coprosma virescens*	**5**
Coprosma crassifolia	**5**	*Coprosma rotundifolia*	**8**	*Teucridium parvifolium*	**5**
Coprosma propinqua	**5**	*Coprosma rubra*	**8**		
Coprosma rotundifolia	**5**	*Coprosma virescens*	**8**		
Coprosma rubra	**5**	*Teucridium parvifolium*	**8**		
Coprosma virescens	**5**				
Total	**750**		**2009**		**1500**

A.2 The insect species driving the differences between plant species in their flower visitor communities

The following tables show the results of a SIMPER analysis on the insect flower visitor composition and plant species, using Bray-Curtis dissimilarities. Each table shows the flower visitor species from a pair of plant species ordered by their contribution to separate the insect communities on the two plants. The column “average” displays the average contribution an insect makes to the overall dissimilarity between the communities on the two plant species. “sd” is the standard deviation of this contribution. “consum” is the comulative sum of the averages. “ratio” is the ratio of the average to the standard deviation. “ava” is the average abundance on the first plant species. “ avb” is the average abundance on the second species.

A.2

Contrast: *Veronica salicifolia - Cordyline australis*

	average	sd	ratio	ava	avb	cumsum
Honey bees	0.140	0.120	1.159	3.946	4.750	0.173
March fly	0.137	0.144	0.952	0.000	4.778	0.343
Lasioglossum	0.113	0.117	0.966	3.703	1.667	0.482
Brown Blow fly	0.094	0.154	0.609	0.000	5.417	0.598
Blue Blow fly	0.058	0.062	0.933	0.270	2.722	0.671
Black Hoverfly	0.056	0.074	0.758	0.162	1.972	0.740
Drone fly	0.034	0.051	0.682	0.851	0.750	0.783
Other Muscid	0.029	0.053	0.556	0.135	0.917	0.820
Leioproctus	0.024	0.054	0.455	0.568	0.139	0.850
Green soldier fly	0.018	0.037	0.494	0.338	0.250	0.872
Green Blow fly	0.018	0.030	0.583	0.162	0.611	0.894
Orange Hoverfly	0.015	0.039	0.398	0.432	0.083	0.913
B. terrestris	0.013	0.027	0.475	0.216	0.194	0.929
Yellow ad	0.011	0.023	0.484	0.297	0.083	0.943
Striped thorax fly	0.007	0.020	0.367	0.189	0.083	0.952
Other Calliphorid	0.006	0.024	0.247	0.054	0.167	0.960
NZ Blue Blow fly	0.005	0.018	0.302	0.149	0.056	0.966
Bronze thorax fly	0.005	0.024	0.210	0.000	0.111	0.973
Robber fly	0.005	0.027	0.183	0.000	0.083	0.979
Euro Blue Blow fly	0.003	0.012	0.235	0.000	0.083	0.982
Other Lep	0.003	0.013	0.198	0.068	0.000	0.985
Ginger Blister fly	0.002	0.007	0.295	0.000	0.083	0.987
Common House fly	0.002	0.007	0.258	0.014	0.083	0.990
Hyaeus	0.001	0.007	0.186	0.054	0.000	0.991
Other Tachinidae	0.001	0.008	0.150	0.041	0.000	0.993
Other wasp	0.001	0.008	0.132	0.027	0.000	0.994
Other beetle	0.001	0.005	0.166	0.000	0.028	0.995
Grey-black tachinid	0.001	0.007	0.112	0.041	0.000	0.996
Other Syrphidae	0.001	0.010	0.085	0.014	0.000	0.997
Green hoverfly	0.001	0.004	0.166	0.000	0.028	0.998
11 spot lady	0.001	0.004	0.153	0.027	0.000	0.999
Three lined Hoverfly	0.000	0.005	0.103	0.014	0.000	0.999
Cabbage white	0.000	0.004	0.104	0.014	0.000	1.000
Blue Muscid	0.000	0.000	NaN	0.000	0.000	1.000
Black Soldier fly	0.000	0.000	NaN	0.000	0.000	1.000
Tabanid	0.000	0.000	NaN	0.000	0.000	1.000
Long tongue bumble	0.000	0.000	NaN	0.000	0.000	1.000

Contrast: *Veronica salicifolia - Leptospermum scoparium*

	average	sd	ratio	ava	avb	cumsum
Honey bees	0.188	0.158	1.195	3.946	1.097	0.206
Lasioglossum	0.185	0.159	1.165	3.703	0.065	0.408
Black Hoverfly	0.126	0.167	0.758	0.162	2.742	0.546
Blue Blow fly	0.080	0.117	0.687	0.270	1.774	0.633
Leioproctus	0.055	0.117	0.466	0.568	0.355	0.693
Drone fly	0.046	0.077	0.599	0.851	0.194	0.743
March fly	0.030	0.109	0.274	0.000	0.677	0.776
Green soldier fly	0.026	0.044	0.577	0.338	0.129	0.804
Brown Blow fly	0.026	0.065	0.394	0.000	0.548	0.831
Green Blow fly	0.022	0.041	0.530	0.162	0.323	0.855
Orange Hoverfly	0.021	0.056	0.378	0.432	0.000	0.878
Other Muscid	0.017	0.045	0.373	0.135	0.129	0.897
Yellow ad	0.016	0.035	0.462	0.297	0.000	0.915
Euro Blue Blow fly	0.014	0.042	0.343	0.000	0.258	0.930
Other wasp	0.014	0.040	0.349	0.027	0.258	0.946
B. terrestris	0.013	0.032	0.401	0.216	0.000	0.960
Striped thorax fly	0.009	0.030	0.303	0.189	0.000	0.970
NZ Blue Blow fly	0.008	0.025	0.308	0.149	0.065	0.978
Other Lep	0.004	0.021	0.211	0.068	0.000	0.983
Other Calliphorid	0.004	0.020	0.190	0.054	0.000	0.987
11 spot lady	0.003	0.015	0.213	0.027	0.032	0.991
Other Tachinidae	0.002	0.011	0.160	0.041	0.000	0.993
Hyaeus	0.002	0.009	0.193	0.054	0.000	0.995
Other Syrphidae	0.002	0.017	0.102	0.014	0.000	0.996
Grey-black tachinid	0.001	0.010	0.115	0.041	0.000	0.998
Three lined Hoverfly	0.001	0.007	0.111	0.014	0.000	0.998
Cabbage white	0.001	0.007	0.112	0.014	0.000	0.999
Common House fly	0.001	0.006	0.112	0.014	0.000	1.000
Bronze thorax fly	0.000	0.000	NaN	0.000	0.000	1.000
Blue Muscid	0.000	0.000	NaN	0.000	0.000	1.000
Ginger Blister fly	0.000	0.000	NaN	0.000	0.000	1.000
Black Soldier fly	0.000	0.000	NaN	0.000	0.000	1.000
Tabanid	0.000	0.000	NaN	0.000	0.000	1.000
Robber fly	0.000	0.000	NaN	0.000	0.000	1.000
Other beetle	0.000	0.000	NaN	0.000	0.000	1.000
Long tongue bumble	0.000	0.000	NaN	0.000	0.000	1.000
Green hoverfly	0.000	0.000	NaN	0.000	0.000	1.000

Contrast: *Hebe salicifolia - Ozothamnus leptophyllus*

	Average	sd	ratio	ava	avb	cumsum
Black Hoverfly	0.175	0.192	0.913	0.162	4.732	0.202
Lasioglossum	0.160	0.137	1.163	3.703	1.634	0.386
Honey bees	0.155	0.140	1.104	3.946	0.171	0.564
Other Muscid	0.053	0.083	0.638	0.135	1.073	0.625
Green soldier fly	0.052	0.074	0.698	0.338	1.268	0.685
Drone fly	0.041	0.066	0.624	0.851	0.293	0.733
Leioproctus	0.034	0.071	0.487	0.568	0.146	0.772
Striped thorax fly	0.027	0.072	0.376	0.189	0.463	0.803
Orange Hoverfly	0.025	0.050	0.505	0.432	0.220	0.833
Blue Blow fly	0.022	0.037	0.607	0.270	0.439	0.858
Green Blow fly	0.019	0.038	0.511	0.162	0.366	0.880
Other Calliphorid	0.016	0.045	0.353	0.054	0.317	0.899
B. terrestris	0.014	0.030	0.476	0.216	0.146	0.915
Yellow ad	0.014	0.029	0.481	0.297	0.024	0.931
11 spot lady	0.013	0.034	0.373	0.027	0.220	0.946
Other Syrphidae	0.011	0.039	0.283	0.014	0.366	0.959
NZ Blue Blow fly	0.005	0.021	0.256	0.149	0.000	0.965
Brown Blow fly	0.005	0.021	0.232	0.000	0.098	0.971
Blue Muscid	0.004	0.019	0.197	0.000	0.098	0.975
March fly	0.004	0.020	0.182	0.000	0.073	0.979
Other Lep	0.004	0.016	0.217	0.068	0.000	0.983
Other Tachinidae	0.003	0.012	0.218	0.041	0.024	0.986
Common House fly	0.002	0.012	0.187	0.014	0.049	0.989
Hyaeus	0.002	0.008	0.192	0.054	0.000	0.991
Other wasp	0.002	0.011	0.144	0.027	0.000	0.993
Tabanid	0.001	0.009	0.149	0.000	0.024	0.994
Ginger Blister fly	0.001	0.007	0.152	0.000	0.024	0.995
Black Soldier fly	0.001	0.007	0.152	0.000	0.024	0.997
Grey-black tachinid	0.001	0.009	0.115	0.041	0.000	0.998
Robber fly	0.001	0.004	0.155	0.000	0.024	0.999
Three lined Hoverfly	0.001	0.006	0.111	0.014	0.000	0.999
Cabbage white	0.001	0.006	0.111	0.014	0.000	1.000
Euro Blue Blow fly	0.000	0.000	NaN	0.000	0.000	1.000
Bronze thorax fly	0.000	0.000	NaN	0.000	0.000	1.000
Other beetle	0.000	0.000	NaN	0.000	0.000	1.000
Long tongue bumble	0.000	0.000	NaN	0.000	0.000	1.000
Green hoverfly	0.000	0.000	NaN	0.000	0.000	1.000

Contrast: *Hebe salicifolia - Chamichaelia australis*

	average	sd	ratio	ava	avb	cumsum
Leioproctus	0.232	0.220	1.057	0.568	4.136	0.267
Lasioglossum	0.224	0.186	1.200	3.703	1.682	0.523
Honey bees	0.195	0.160	1.216	3.946	1.182	0.747
Drone fly	0.042	0.076	0.554	0.851	0.000	0.796
Green soldier fly	0.023	0.041	0.559	0.338	0.045	0.822
Orange Hoverfly	0.021	0.055	0.387	0.432	0.000	0.846
Yellow ad	0.016	0.034	0.475	0.297	0.000	0.865
Black Hoverfly	0.016	0.048	0.337	0.162	0.091	0.884
B. terrestris	0.013	0.032	0.414	0.216	0.000	0.899
Blue Blow fly	0.011	0.031	0.365	0.270	0.000	0.912
Striped thorax fly	0.009	0.030	0.310	0.189	0.000	0.922
March fly	0.009	0.050	0.182	0.000	0.091	0.933
Green Blow fly	0.008	0.025	0.336	0.162	0.000	0.943
Other Muscid	0.008	0.031	0.267	0.135	0.000	0.952
11 spot lady	0.007	0.023	0.288	0.027	0.091	0.960
NZ Blue Blow fly	0.006	0.025	0.260	0.149	0.000	0.967
Other wasp	0.006	0.024	0.237	0.027	0.045	0.974
Robber fly	0.005	0.025	0.182	0.000	0.045	0.979
Other Lep	0.004	0.020	0.222	0.068	0.000	0.984
Other Calliphorid	0.004	0.018	0.200	0.054	0.000	0.988
Hyaeus	0.003	0.012	0.287	0.054	0.045	0.992
Other Tachinidae	0.002	0.011	0.162	0.041	0.000	0.994
Other Syrphidae	0.002	0.016	0.107	0.014	0.000	0.996
Grey-black tachinid	0.001	0.010	0.116	0.041	0.000	0.997
Three lined Hoverfly	0.001	0.007	0.113	0.014	0.000	0.998
Cabbage white	0.001	0.007	0.114	0.014	0.000	0.999
Common House fly	0.001	0.006	0.114	0.014	0.000	1.000
Brown Blow fly	0.000	0.000	NaN	0.000	0.000	1.000
Euro Blue Blow fly	0.000	0.000	NaN	0.000	0.000	1.000
Bronze thorax fly	0.000	0.000	NaN	0.000	0.000	1.000
Blue Muscid	0.000	0.000	NaN	0.000	0.000	1.000
Ginger Blister fly	0.000	0.000	NaN	0.000	0.000	1.000
Black Soldier fly	0.000	0.000	NaN	0.000	0.000	1.000
Tabanid	0.000	0.000	NaN	0.000	0.000	1.000
Other beetle	0.000	0.000	NaN	0.000	0.000	1.000
Long tongue bumble	0.000	0.000	NaN	0.000	0.000	1.000
Green hoverfly	0.000	0.000	NaN	0.000	0.000	1.000

Contrast: *Hebe salicifolia* - *Phormium tenax*

	average	sd	ratio	ava	avb	cumsum
Lasioglossum	0.205	0.167	1.231	3.703	0.656	0.263
Honey bees	0.204	0.163	1.250	3.946	1.719	0.525
Leioproctus	0.052	0.099	0.529	0.568	0.156	0.592
Drone fly	0.049	0.086	0.566	0.851	0.000	0.654
Black Hoverfly	0.032	0.080	0.395	0.162	0.281	0.695
B. terrestris	0.030	0.062	0.481	0.216	0.281	0.733
March fly	0.027	0.096	0.281	0.000	0.563	0.768
Green soldier fly	0.026	0.049	0.544	0.338	0.000	0.802
Orange Hoverfly	0.025	0.063	0.394	0.432	0.000	0.833
Blue Blow fly	0.022	0.056	0.396	0.270	0.188	0.862
Yellow ad	0.019	0.040	0.478	0.297	0.000	0.886
Other Muscid	0.017	0.056	0.294	0.135	0.094	0.907
Striped thorax fly	0.011	0.034	0.311	0.189	0.000	0.921
Green Blow fly	0.010	0.029	0.339	0.162	0.000	0.933
Other Calliphorid	0.008	0.027	0.292	0.054	0.063	0.943
Long tongue bumble	0.008	0.044	0.171	0.000	0.156	0.953
NZ Blue Blow fly	0.007	0.028	0.261	0.149	0.000	0.963
11 spot lady	0.006	0.025	0.249	0.027	0.063	0.971
Other Lep	0.005	0.024	0.220	0.068	0.000	0.978
Bronze thorax fly	0.004	0.027	0.140	0.000	0.031	0.982
Other wasp	0.002	0.015	0.149	0.027	0.000	0.985
Other Syrphidae	0.002	0.020	0.110	0.014	0.000	0.988
Other Tachinidae	0.002	0.013	0.164	0.041	0.000	0.991
Hyaeus	0.002	0.010	0.196	0.054	0.000	0.993
Brown Blow fly	0.001	0.008	0.172	0.000	0.031	0.995
Grey-black tachinid	0.001	0.011	0.117	0.041	0.000	0.997
Three lined Hoverfly	0.001	0.008	0.115	0.014	0.000	0.998
Cabbage white	0.001	0.007	0.115	0.014	0.000	0.999
Common House fly	0.001	0.007	0.116	0.014	0.000	1.000
Euro Blue Blow fly	0.000	0.000	NaN	0.000	0.000	1.000
Blue Muscid	0.000	0.000	NaN	0.000	0.000	1.000
Ginger Blister fly	0.000	0.000	NaN	0.000	0.000	1.000
Black Soldier fly	0.000	0.000	NaN	0.000	0.000	1.000
Tabanid	0.000	0.000	NaN	0.000	0.000	1.000
Robber fly	0.000	0.000	NaN	0.000	0.000	1.000
Other beetle	0.000	0.000	NaN	0.000	0.000	1.000
Green hoverfly	0.000	0.000	NaN	0.000	0.000	1.000

Contrast: *Hebe salicifolia - Kunzea serotina*

	average	sd	ratio	ava	avb	cumsum
Honey bees	0.183	0.150	1.220	3.946	0.4375 0	0.220
Lasioglossum	0.171	0.140	1.217	3.703	1.1875 0	0.424
Black Hoverfly	0.163	0.183	0.890	0.162	3.0000 0	0.619
Leioproctus	0.064	0.114	0.557	0.568	0.6875 0	0.696
Green soldier fly	0.058	0.085	0.676	0.338	0.7500 0	0.765
Drone fly	0.045	0.073	0.613	0.851	0.1250 0	0.818
Orange Hoverfly	0.023	0.053	0.434	0.432	0.0625 0	0.846
Striped thorax fly	0.018	0.049	0.364	0.189	0.1250 0	0.867
Blue Blow fly	0.017	0.035	0.499	0.270	0.1250 0	0.888
Yellow ad	0.016	0.033	0.486	0.297	0.0000 0	0.907
Other Muscid	0.014	0.033	0.428	0.135	0.1250 0	0.924
B. terrestris	0.013	0.030	0.424	0.216	0.0000 0	0.940
Green Blow fly	0.012	0.029	0.410	0.162	0.0625 0	0.954
NZ Blue Blow fly	0.006	0.024	0.264	0.149	0.0000 0	0.962
March fly	0.006	0.017	0.354	0.000	0.1250 0	0.969
Other Syrphidae	0.006	0.023	0.254	0.014	0.0625 0	0.976
Other Lep	0.004	0.018	0.230	0.068	0.0000 0	0.981
Other Calliphorid	0.004	0.017	0.207	0.054	0.0000 0	0.985
Tabanid	0.003	0.011	0.249	0.000	0.0625 0	0.988
Other wasp	0.002	0.012	0.152	0.027	0.0000 0	0.991
Other Tachinidae	0.002	0.011	0.164	0.041	0.0000 0	0.993
Hyaeus	0.002	0.009	0.196	0.054	0.0000 0	0.995
Grey-black tachinid	0.001	0.010	0.116	0.041	0.0000 0	0.996
11 spot lady	0.001	0.006	0.161	0.027	0.0000 0	0.997
Three lined Hoverfly	0.001	0.007	0.115	0.014	0.0000 0	0.998
Cabbage white	0.001	0.006	0.115	0.014	0.0000 0	0.999
Common House fly	0.001	0.006	0.115	0.014	0.0000 1	0.000
Brown Blow fly	0.000	0.000	NaN	0.000	0.0000 1	0.000
Euro Blue Blow fly	0.000	0.000	NaN	0.000	0.0000 1	0.000
Bronze thorax fly	0.000	0.000	NaN	0.000	0.0000 1	0.000
Blue Muscid	0.000	0.000	NaN	0.000	0.0000 1	0.000
Ginger Blister fly	0.000	0.000	NaN	0.000	0.0000 1	0.000
Black Soldier fly	0.000	0.000	NaN	0.000	0.0000 1	0.000
Robber fly	0.000	0.000	NaN	0.000	0.0000 1	0.000
Other beetle	0.000	0.000	NaN	0.000	0.0000 1	0.000
Long tongue bumble	0.000	0.000	NaN	0.000	0.0000 1	0.000
Green hoverfly	0.000	0.000	NaN	0.000	0.0000 1	0.000

Contrast: *Cordyline australis - Leptospermum scoparium*

	average	sd	ratio	ava	avb	cumsum
March fly	0.161	0.168	0.961	4.778	0.677	0.189
Honey bees	0.152	0.131	1.164	4.750	1.097	0.368
Black Hoverfly	0.109	0.136	0.804	1.972	2.742	0.496
Brown Blow fly	0.108	0.162	0.668	5.417	0.548	0.623
Blue Blow fly	0.090	0.098	0.917	2.722	1.774	0.729
Lasioglossum	0.049	0.076	0.638	1.667	0.065	0.786
Other Muscid	0.035	0.063	0.549	0.917	0.129	0.827
Green Blow fly	0.024	0.040	0.602	0.611	0.323	0.855
Drone fly	0.022	0.030	0.733	0.750	0.194	0.881
Leioproctus	0.020	0.077	0.261	0.139	0.355	0.904
Green soldier fly	0.015	0.048	0.311	0.250	0.129	0.922
Euro Blue Blow fly	0.013	0.034	0.367	0.083	0.258	0.936
Other wasp	0.009	0.034	0.270	0.000	0.258	0.947
B. terrestris	0.008	0.025	0.309	0.194	0.000	0.956
Robber fly	0.007	0.042	0.171	0.083	0.000	0.965
Bronze thorax fly	0.006	0.031	0.202	0.111	0.000	0.972
Orange Hoverfly	0.004	0.021	0.215	0.083	0.000	0.977
Other Calliphorid	0.004	0.024	0.184	0.167	0.000	0.983
NZ Blue Blow fly	0.003	0.009	0.312	0.056	0.065	0.986
Yellow ad	0.003	0.009	0.295	0.083	0.000	0.989
Striped thorax fly	0.002	0.008	0.295	0.083	0.000	0.992
Ginger Blister fly	0.002	0.007	0.294	0.083	0.000	0.994
11 spot lady	0.002	0.011	0.144	0.000	0.032	0.996
Common House fly	0.002	0.007	0.239	0.083	0.000	0.998
Other beetle	0.001	0.006	0.165	0.028	0.000	0.999
Green hoverfly	0.001	0.005	0.166	0.028	0.000	1.000
Blue Muscid	0.000	0.000	NaN	0.000	0.000	1.000
Grey-black tachinid	0.000	0.000	NaN	0.000	0.000	1.000
Other Tachinidae	0.000	0.000	NaN	0.000	0.000	1.000
Three lined Hoverfly	0.000	0.000	NaN	0.000	0.000	1.000
Black Soldier fly	0.000	0.000	NaN	0.000	0.000	1.000
Other Syrphidae	0.000	0.000	NaN	0.000	0.000	1.000
Tabanid	0.000	0.000	NaN	0.000	0.000	1.000
Cabbage white	0.000	0.000	NaN	0.000	0.000	1.000
Other Lep	0.000	0.000	NaN	0.000	0.000	1.000
Long tongue bumble	0.000	0.000	NaN	0.000	0.000	1.000
Hyaeus	0.000	0.000	NaN	0.000	0.000	1.000

Contrast*: Cordyline australis - Ozothamnus leptophyllus*

	average	sd	ratio	ava	avb	cumsum
Black Hoverfly	0.137	0.152	0.904	1.972	4.732	0.157
March fly	0.137	0.145	0.945	4.778	0.073	0.313
Honey bees	0.132	0.114	1.162	4.750	0.171	0.465
Brown Blow fly	0.094	0.153	0.616	5.417	0.098	0.573
Lasioglossum	0.077	0.107	0.721	1.667	1.634	0.661
Blue Blow fly	0.059	0.061	0.965	2.722	0.439	0.728
Other Muscid	0.049	0.073	0.682	0.917	1.073	0.785
Green soldier fly	0.038	0.066	0.579	0.250	1.268	0.829
Drone fly	0.022	0.029	0.746	0.750	0.293	0.854
Green Blow fly	0.022	0.036	0.608	0.611	0.366	0.879
Striped thorax fly	0.017	0.056	0.306	0.083	0.463	0.898
Other Calliphorid	0.013	0.040	0.338	0.167	0.317	0.914
Orange Hoverfly	0.010	0.027	0.381	0.083	0.220	0.925
B. terrestris	0.010	0.025	0.388	0.194	0.146	0.936
Leioproctus	0.009	0.028	0.317	0.139	0.146	0.947
11 spot lady	0.009	0.030	0.292	0.000	0.220	0.957
Other Syrphidae	0.008	0.031	0.254	0.000	0.366	0.966
Robber fly	0.006	0.029	0.188	0.083	0.024	0.972
Bronze thorax fly	0.005	0.025	0.206	0.111	0.000	0.978
Yellow ad	0.003	0.009	0.327	0.083	0.024	0.981
Blue Muscid	0.003	0.015	0.185	0.000	0.098	0.984
Common House fly	0.003	0.011	0.256	0.083	0.049	0.988
Euro Blue Blow fly	0.003	0.012	0.233	0.083	0.000	0.991
Ginger Blister fly	0.003	0.008	0.316	0.083	0.024	0.994
NZ Blue Blow fly	0.001	0.007	0.212	0.056	0.000	0.995
Tabanid	0.001	0.007	0.136	0.000	0.024	0.996
Other beetle	0.001	0.005	0.165	0.028	0.000	0.997
Other Tachinidae	0.001	0.006	0.142	0.000	0.024	0.998
Black Soldier fly	0.001	0.006	0.142	0.000	0.024	0.999
Green hoverfly	0.001	0.004	0.166	0.028	0.000	1.000
Grey-black tachinid	0.000	0.000	NaN	0.000	0.000	1.000
Three lined Hoverfly	0.000	0.000	NaN	0.000	0.000	1.000
Cabbage white	0.000	0.000	NaN	0.000	0.000	1.000
Other Lep	0.000	0.000	NaN	0.000	0.000	1.000
Long tongue bumble	0.000	0.000	NaN	0.000	0.000	1.000
Hyaeus	0.000	0.000	NaN	0.000	0.000	1.000
Other wasp	0.000	0.000	NaN	0.000	0.000	1.000

Contrast: *Cordyline australis - Carmichaelia australis*

	average	sd	ratio	ava	avb	cumsum
Leioproctus	0.168	0.199	0.845	0.139	4.136	0.181
March fly	0.158	0.162	0.974	4.778	0.091	0.350
Honey bees	0.157	0.135	1.161	4.750	1.182	0.519
Brown Blow fly	0.102	0.163	0.624	5.417	0.000	0.629
Lasioglossum	0.084	0.150	0.562	1.667	1.682	0.719
Black Hoverfly	0.065	0.084	0.769	1.972	0.091	0.789
Blue Blow fly	0.062	0.070	0.889	2.722	0.000	0.856
Other Muscid	0.031	0.059	0.529	0.917	0.000	0.889
Drone fly	0.019	0.026	0.748	0.750	0.000	0.910
Green Blow fly	0.016	0.032	0.508	0.611	0.000	0.928
Green soldier fly	0.012	0.040	0.294	0.250	0.045	0.940
Robber fly	0.009	0.037	0.238	0.083	0.045	0.950
B. terrestris	0.008	0.025	0.314	0.194	0.000	0.958
Bronze thorax fly	0.006	0.030	0.209	0.111	0.000	0.965
Orange Hoverfly	0.004	0.020	0.225	0.083	0.000	0.970
Other Calliphorid	0.004	0.024	0.185	0.167	0.000	0.975
11 spot lady	0.004	0.019	0.221	0.000	0.091	0.979
Euro Blue Blow fly	0.003	0.013	0.237	0.083	0.000	0.982
Other wasp	0.003	0.017	0.157	0.000	0.045	0.985
Yellow ad	0.003	0.009	0.297	0.083	0.000	0.988
Striped thorax fly	0.003	0.009	0.297	0.083	0.000	0.991
Ginger Blister fly	0.002	0.007	0.296	0.083	0.000	0.993
NZ Blue Blow fly	0.002	0.008	0.212	0.056	0.000	0.995
Common House fly	0.002	0.007	0.240	0.083	0.000	0.997
Hyaeus	0.001	0.007	0.198	0.000	0.045	0.998
Other beetle	0.001	0.006	0.167	0.028	0.000	0.999
Green hoverfly	0.001	0.005	0.167	0.028	0.000	1.000
Blue Muscid	0.000	0.000	NaN	0.000	0.000	1.000
Grey-black tachinid	0.000	0.000	NaN	0.000	0.000	1.000
Other Tachinidae	0.000	0.000	NaN	0.000	0.000	1.000
Three lined Hoverfly	0.000	0.000	NaN	0.000	0.000	1.000
Black Soldier fly	0.000	0.000	NaN	0.000	0.000	1.000
Other Syrphidae	0.000	0.000	NaN	0.000	0.000	1.000
Tabanid	0.000	0.000	NaN	0.000	0.000	1.000
Cabbage white	0.000	0.000	NaN	0.000	0.000	1.000
Other Lep	0.000	0.000	NaN	0.000	0.000	1.000
Long tongue bumble	0.000	0.000	NaN	0.000	0.000	1.000

Contrast: *Cordyline australis – Phormium tenax*

	average	sd	ratio	ava	avb	cumsum
March fly	0.178	0.180	0.991	4.778	0.563	0.211
Honey bees	0.164	0.143	1.146	4.750	1.719	0.405
Brown Blow fly	0.109	0.170	0.639	5.417	0.031	0.533
Black Hoverfly	0.075	0.099	0.759	1.972	0.281	0.622
Blue Blow fly	0.071	0.078	0.907	2.722	0.188	0.705
Lasioglossum	0.068	0.094	0.730	1.667	0.656	0.786
Other Muscid	0.038	0.070	0.541	0.917	0.094	0.831
Drone fly	0.021	0.028	0.751	0.750	0.000	0.855
B. terrestris	0.019	0.050	0.388	0.194	0.281	0.878
Green Blow fly	0.018	0.035	0.511	0.611	0.000	0.899
Leioproctus	0.014	0.044	0.324	0.139	0.156	0.916
Green soldier fly	0.014	0.054	0.253	0.250	0.000	0.932
Bronze thorax fly	0.010	0.042	0.230	0.111	0.031	0.943
Robber fly	0.009	0.050	0.183	0.083	0.000	0.954
Other Calliphorid	0.007	0.028	0.259	0.167	0.063	0.963
Long tongue bumble	0.006	0.035	0.158	0.000	0.156	0.969
Orange Hoverfly	0.005	0.024	0.222	0.083	0.000	0.976
11 spot lady	0.004	0.021	0.178	0.000	0.063	0.980
Euro Blue Blow fly	0.004	0.015	0.240	0.083	0.000	0.984
Yellow ad	0.003	0.009	0.300	0.083	0.000	0.988
Striped thorax fly	0.003	0.009	0.299	0.083	0.000	0.991
Ginger Blister fly	0.002	0.008	0.298	0.083	0.000	0.994
NZ Blue Blow fly	0.002	0.009	0.212	0.056	0.000	0.996
Common House fly	0.002	0.007	0.241	0.083	0.000	0.998
Other beetle	0.001	0.006	0.168	0.028	0.000	0.999
Green hoverfly	0.001	0.005	0.168	0.028	0.000	1.000
Blue Muscid	0.000	0.000	NaN	0.000	0.000	1.000
Grey-black tachinid	0.000	0.000	NaN	0.000	0.000	1.000
Other Tachinidae	0.000	0.000	NaN	0.000	0.000	1.000
Three lined Hoverfly	0.000	0.000	NaN	0.000	0.000	1.000
Black Soldier fly	0.000	0.000	NaN	0.000	0.000	1.000
Other Syrphidae	0.000	0.000	NaN	0.000	0.000	1.000
Tabanid	0.000	0.000	NaN	0.000	0.000	1.000
Cabbage white	0.000	0.000	NaN	0.000	0.000	1.000
Other Lep	0.000	0.000	NaN	0.000	0.000	1.000
Hyaeus	0.000	0.000	NaN	0.000	0.000	1.000
Other wasp	0.000	0.000	NaN	0.000	0.000	1.000

Contrast: *Cordyline australis – Kunzea serotina*

	average	sd	ratio	ava	avb c	umsum
March fly	0.155	0.157	0.987	4.778	0.1250 0	0.178
Honey bees	0.150	0.124	1.212	4.750	0.4375 0	0.351
Black Hoverfly	0.123	0.147	0.836	1.972	3.0000 0	0.492
Brown Blow fly	0.102	0.163	0.625	5.417	0.0000 0	0.609
Lasioglossum	0.076	0.102	0.742	1.667	1.1875 0	0.696
Blue Blow fly	0.064	0.068	0.942	2.722	0.1250 0	0.769
Green soldier fly	0.041	0.073	0.561	0.250	0.7500 0	0.816
Other Muscid	0.033	0.058	0.581	0.917	0.1250 0	0.855
Leioproctus	0.029	0.081	0.357	0.139	0.6875 0	0.888
Drone fly	0.022	0.027	0.801	0.750	0.1250 0	0.913
Green Blow fly	0.018	0.033	0.546	0.611	0.0625 0	0.934
Striped thorax fly	0.009	0.035	0.256	0.083	0.1250 0	0.944
B. terrestris	0.008	0.024	0.317	0.194	0.0000 0	0.953
Bronze thorax fly	0.006	0.029	0.215	0.111	0.0000 0	0.960
Orange Hoverfly	0.006	0.020	0.307	0.083	0.0625 0	0.967
Robber fly	0.006	0.030	0.200	0.083	0.0000 0	0.974
Other Calliphorid	0.004	0.024	0.186	0.167	0.0000 0	0.979
Euro Blue Blow fly	0.003	0.013	0.239	0.083	0.0000 0	0.983
Other Syrphidae	0.003	0.015	0.203	0.000	0.0625 0	0.987
Yellow ad	0.003	0.009	0.299	0.083	0.0000 0	0.990
Ginger Blister fly	0.002	0.007	0.297	0.083	0.0000 0	0.992
Tabanid	0.002	0.008	0.233	0.000	0.0625 0	0.994
NZ Blue Blow fly	0.002	0.008	0.214	0.056	0.0000 0	0.996
Common House fly	0.002	0.007	0.241	0.083	0.0000 0	0.998
Other beetle	0.001	0.006	0.168	0.028	0.0000 0	0.999
Green hoverfly	0.001	0.005	0.168	0.028	0.0000 1	0.000
Blue Muscid	0.000	0.000	NaN	0.000	0.0000 1	0.000
Grey-black tachinid	0.000	0.000	NaN	0.000	0.0000 1	0.000
Other Tachinidae	0.000	0.000	NaN	0.000	0.0000 1	0.000
Three lined Hoverfly	0.000	0.000	NaN	0.000	0.0000 1	0.000
Black Soldier fly	0.000	0.000	NaN	0.000	0.0000 1	0.000
11 spot lady	0.000	0.000	NaN	0.000	0.0000 1	0.000
Cabbage white	0.000	0.000	NaN	0.000	0.0000 1	0.000
Other Lep	0.000	0.000	NaN	0.000	0.0000 1	0.000
Long tongue bumble	0.000	0.000	NaN	0.000	0.0000 1	0.000
Hyaeus	0.000	0.000	NaN	0.000	0.0000 1	0.000
Other wasp	0.000	0.000	NaN	0.000	0.0000 1	0.000

Contrast: *Leptospermum scoparium - Ozothamnus leptophyllus*

	average	sd	ratio	ava	avb	cumsum
Black Hoverfly	0.240	0.217	1.104	2.742	4.732	0.277
Lasioglossum	0.099	0.159	0.622	0.065	1.634	0.391
Blue Blow fly	0.083	0.118	0.708	1.774	0.439	0.487
Other Muscid	0.066	0.105	0.631	0.129	1.073	0.563
Green soldier fly	0.055	0.090	0.611	0.129	1.268	0.627
Honey bees	0.050	0.093	0.540	1.097	0.171	0.685
March fly	0.034	0.111	0.304	0.677	0.073	0.724
Brown Blow fly	0.030	0.071	0.423	0.548	0.098	0.759
Green Blow fly	0.029	0.052	0.560	0.323	0.366	0.793
Leioproctus	0.027	0.101	0.269	0.355	0.146	0.824
Striped thorax fly	0.025	0.087	0.289	0.000	0.463	0.853
Drone fly	0.021	0.043	0.483	0.194	0.293	0.877
11 spot lady	0.018	0.052	0.349	0.032	0.220	0.898
Other Calliphorid	0.016	0.054	0.296	0.000	0.317	0.917
Euro Blue Blow fly	0.014	0.043	0.337	0.258	0.000	0.933
Orange Hoverfly	0.014	0.039	0.347	0.000	0.220	0.949
Other wasp	0.013	0.042	0.311	0.258	0.000	0.964
Other Syrphidae	0.011	0.041	0.268	0.000	0.366	0.977
B. terrestris	0.005	0.021	0.242	0.000	0.146	0.983
Blue Muscid	0.004	0.022	0.196	0.000	0.098	0.988
Common House fly	0.002	0.013	0.154	0.000	0.049	0.990
NZ Blue Blow fly	0.002	0.006	0.257	0.065	0.000	0.992
Tabanid	0.002	0.011	0.149	0.000	0.024	0.994
Ginger Blister fly	0.001	0.008	0.152	0.000	0.024	0.995
Other Tachinidae	0.001	0.008	0.152	0.000	0.024	0.997
Black Soldier fly	0.001	0.008	0.152	0.000	0.024	0.998
Yellow ad	0.001	0.007	0.153	0.000	0.024	0.999
Robber fly	0.001	0.005	0.155	0.000	0.024	1.000
Bronze thorax fly	0.000	0.000	NaN	0.000	0.000	1.000
Grey-black tachinid	0.000	0.000	NaN	0.000	0.000	1.000
Three lined Hoverfly	0.000	0.000	NaN	0.000	0.000	1.000
Other beetle	0.000	0.000	NaN	0.000	0.000	1.000
Cabbage white	0.000	0.000	NaN	0.000	0.000	1.000
Other Lep	0.000	0.000	NaN	0.000	0.000	1.000
Long tongue bumble	0.000	0.000	NaN	0.000	0.000	1.000
Hyaeus	0.000	0.000	NaN	0.000	0.000	1.000
Green hoverfly	0.000	0.000	NaN	0.000	0.000	1.000

Contrast: *Leptospermum scoparium - Carmichaelia australis*

	average	sd	ratio	ava	avb c	umsum
Leioproctus	0.311	0.289	1.0780 0	.35484 4	.13636 0	0.329
Black Hoverfly	0.153	0.198	0.7722 2	.74194 0	.09091 0	0.490
Honey bees	0.121	0.175	0.6926 1	.09677 1	.18182 0	0.618
Blue Blow fly	0.093	0.143	0.6522 1	.77419 0	.00000 0	0.717
Lasioglossum	0.071	0.209	0.3373 0	.06452 1	.68182 0	0.791
March fly	0.049	0.144	0.3375 0	.67742 0	.09091 0	0.842
Brown Blow fly	0.033	0.084	0.3903 0	.54839 0	.00000 0	0.877
Green Blow fly	0.021	0.048	0.4363 0	.32258 0	.00000 0	0.899
Other wasp	0.021	0.054	0.3825 0	.25806 0	.04545 0	0.921
Euro Blue Blow fly	0.018	0.051	0.3492 0	.25806 0	.00000 0	0.940
Other Muscid	0.015	0.049	0.3043 0	.12903 0	.00000 0	0.955
Drone fly	0.011	0.033	0.3378 0	.19355 0	.00000 0	0.967
11 spot ladybug	0.010	0.035	0.2969 0	.03226 0	.09091 0	0.978
Green soldier fly	0.010	0.029	0.3377 0	.12903 0	.04545 0	0.988
Robber fly	0.007	0.038	0.1832 0	.00000 0	.04545 0	0.996
Hyaeus	0.002	0.010	0.2102 0	.00000 0	.04545 0	0.998
NZ Blue Blow fly	0.002	0.007	0.2595 0	.06452 0	.00000 1	0.000
Bronze thorax fly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Other Calliphorid	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Blue Muscid	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Common House fly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Striped thorax fly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Ginger Blister fly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Grey-black tachinid	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Other Tachinidae	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Orange Hoverfly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Three lined Hoverfly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Black Soldier fly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Other Syrphidae	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Tabanid	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Other beetle	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Cabbage white	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Yellow ad	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Other Lep	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Long tongue bumble	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
B. terrestris	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Green hoverfly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000

Contrast: *Leptospermum scoparium - Phormium tenax*

	average	sd	ratio	ava	avb c	umsum
Honey bees	0.198	0.183	1.0835 1	.09677 1	.71875 0	0.218
Black Hoverfly	0.188	0.228	0.8241 2	.74194 0	.28125 0	0.424
Blue Blow fly	0.118	0.168	0.7040 1	.77419 0	.18750 0	0.554
Lasioglossum	0.072	0.123	0.5831 0	.06452 0	.65625 0	0.633
March fly	0.070	0.174	0.4035 0	.67742 0	.56250 0	0.710
Leioproctus	0.046	0.145	0.3185 0	.35484 0	.15625 0	0.761
Brown Blow fly	0.042	0.109	0.3867 0	.54839 0	.03125 0	0.808
Other Muscid	0.029	0.084	0.3420 0	.12903 0	.09375 0	0.839
Green Blow fly	0.025	0.058	0.4354 0	.32258 0	.00000 0	0.867
B. terrestris	0.022	0.073	0.3017 0	.00000 0	.28125 0	0.891
Euro Blue Blow fly	0.021	0.060	0.3548 0	.25806 0	.00000 0	0.915
Other wasp	0.021	0.064	0.3271 0	.25806 0	.00000 0	0.938
Drone fly	0.014	0.042	0.3235 0	.19355 0	.00000 0	0.953
11 spot ladybug	0.011	0.041	0.2713 0	.03226 0	.06250 0	0.965
Green soldier fly	0.010	0.033	0.2885 0	.12903 0	.00000 0	0.976
Long tongue bumble	0.009	0.053	0.1708 0	.00000 0	.15625 0	0.986
Bronze thorax fly	0.006	0.044	0.1427 0	.00000 0	.03125 0	0.993
Other Calliphorid	0.005	0.021	0.2288 0	.00000 0	.06250 0	0.998
NZ Blue Blow fly	0.002	0.008	0.2612 0	.06452 0	.00000 1	0.000
Blue Muscid	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Common House fly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Striped thorax fly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Ginger Blister fly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Grey-black tachinid	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Other Tachinidae	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Orange Hoverfly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Three lined Hoverfly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Black Soldier fly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Other Syrphidae	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Tabanid	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Robber fly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Other beetle	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Cabbage white	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Yellow ad	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Other Lep	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Hyaeus	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Green hoverfly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000

Contrast: *Leptospermum scoparium – Kunzea serotina*

	average	sd	ratio	ava	avb cu	msum
Black Hoverfly	0.246	0.227	1.0823 2	.74194 3	.0000 0.	2881.000
Lasioglossum	0.102	0.150	0.6830 0	.06452 1	.1875 0.	4078.000
Blue Blow fly	0.094	0.132	0.7155 1	.77419 0	.1250 0.	5183.000
Green soldier fly	0.077	0.126	0.6146 0	.12903 0	.7500 0.	6091.000
Honey bees	0.071	0.114	0.6231 1	.09677 0	.4375 0.	6927.000
Leioproctus	0.063	0.160	0.3931 0	.35484 0	.6875 0.	7662.000
March fly	0.041	0.124	0.3334 0	.67742 0	.1250 0.	8147.000
Brown Blow fly	0.031	0.076	0.4120 0	.54839 0	.0000 0.	8512.000
Green Blow fly	0.024	0.047	0.5032 0	.32258 0	.0625 0.	8792.000
Other Muscid	0.021	0.048	0.4366 0	.12903 0	.1250 0.	9038.000
Drone fly	0.018	0.036	0.4870 0	.19355 0	.1250 0.	9245.000
Euro Blue Blow fly	0.017	0.049	0.3566 0	.25806 0	.0000 0.	9449.000
Other wasp	0.016	0.045	0.3481 0	.25806 0	.0000 0.	9631.000
Striped thorax fly	0.014	0.060	0.2292 0	.00000 0	.1250 0.	9791.000
Other Syrphidae	0.006	0.026	0.2331 0	.00000 0	.0625 0.	9862.000
Orange Hoverfly	0.004	0.016	0.2438 0	.00000 0	.0625 0.	9908.000
Tabanid	0.003	0.012	0.2478 0	.00000 0	.0625 0.	9943.000
11 spot ladybug	0.003	0.017	0.1750 0	.03226 0	.0000 0.	9978.000
NZ Blue Blow fly	0.002	0.007	0.2608 0	.06452 0	.0000 1.	0.000
Bronze thorax fly	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Other Calliphorid	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Blue Muscid	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Common House fly	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Ginger Blister fly	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Grey-black tachinid	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Other Tachinidae	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Three lined Hoverfly	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Black Soldier fly	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Robber fly	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Other beetle	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Cabbage white	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Yellow ad	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Other Lep	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Long tongue bumble	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
B. terrestris	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Hyaeus	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Green hoverfly	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000

Contrast: *Ozothamnus leptophyllus - Carmichaelia australis*

	average	sd	ratio	ava	avb c	umsum
Leioproctus	0.242	0.239	1.0118 0	.14634 4	.13636 0	0.251
Black Hoverfly	0.208	0.219	0.9468 4	.73171 0	.09091 0	0.465
Lasioglossum	0.143	0.211	0.6783 1	.63415 1	.68182 0	0.614
Honey bees	0.072	0.138	0.5242 0	.17073 1	.18182 0	0.688
Other Muscid	0.063	0.103	0.6132 1	.07317 0	.00000 0	0.753
Green soldier fly	0.053	0.090	0.5955 1	.26829 0	.04545 0	0.809
Striped thorax fly	0.025	0.086	0.2963 0	.46341 0	.00000 0	0.835
11 spot lady	0.019	0.046	0.4233 0	.21951 0	.09091 0	0.855
Blue Blow fly	0.019	0.036	0.5173 0	.43902 0	.00000 0	0.874
Green Blow fly	0.017	0.043	0.4009 0	.36585 0	.00000 0	0.892
Other Calliphorid	0.016	0.053	0.3045 0	.31707 0	.00000 0	0.909
Drone fly	0.014	0.037	0.3965 0	.29268 0	.00000 0	0.924
Orange Hoverfly	0.013	0.037	0.3667 0	.21951 0	.00000 0	0.938
March fly	0.013	0.058	0.2311 0	.07317 0	.09091 0	0.952
Other Syrphidae	0.011	0.042	0.2693 0	.36585 0	.00000 0	0.963
Brown Blow fly	0.006	0.026	0.2334 0	.09756 0	.00000 0	0.969
Robber fly	0.006	0.028	0.1994 0	.02439 0	.04545 0	0.975
B. terrestris	0.005	0.021	0.2461 0	.14634 0	.00000 0	0.980
Blue Muscid	0.004	0.022	0.1987 0	.09756 0	.00000 0	0.985
Other wasp	0.004	0.023	0.1844 0	.00000 0	.04545 0	0.989
Common House fly	0.002	0.013	0.1552 0	.04878 0	.00000 0	0.991
Hyaeus	0.002	0.009	0.2092 0	.00000 0	.04545 0	0.993
Tabanid	0.002	0.011	0.1521 0	.02439 0	.00000 0	0.995
Ginger Blister fly	0.001	0.008	0.1539 0	.02439 0	.00000 0	0.996
Other Tachinidae	0.001	0.008	0.1539 0	.02439 0	.00000 0	0.998
Black Soldier fly	0.001	0.008	0.1539 0	.02439 0	.00000 0	0.999
Yellow ad	0.001	0.007	0.1550 0	.02439 0	.00000 1	0.000
NZ Blue Blow fly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Euro Blue Blow fly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Bronze thorax fly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Grey-black tachinid	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Three lined Hoverfly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Other beetle	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Cabbage white	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Other Lep	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Long tongue bumble	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000
Green hoverfly	0.000	0.000	NaN 0	.00000 0	.00000 1	0.000

Contrast: *Ozothamnus leptophyllus - Phormium tenax*

	average	sd	ratio	ava	avb	cumsum
Black Hoverfly	0.239	0.239	1.001	4.732	0.281	0.260
Honey bees	0.133	0.146	0.914	0.171	1.719	0.404
Lasioglossum	0.131	0.171	0.769	1.634	0.656	0.547
Other Muscid	0.078	0.123	0.635	1.073	0.094	0.632
Green soldier fly	0.060	0.102	0.593	1.268	0.000	0.697
March fly	0.031	0.099	0.318	0.073	0.563	0.731
Blue Blow fly	0.030	0.059	0.508	0.439	0.188	0.764
Striped thorax fly	0.029	0.099	0.298	0.463	0.000	0.796
11 spot lady	0.024	0.061	0.387	0.220	0.063	0.822
B. terrestris	0.022	0.061	0.366	0.146	0.281	0.846
Other Calliphorid	0.022	0.062	0.351	0.317	0.063	0.870
Green Blow fly	0.020	0.050	0.398	0.366	0.000	0.891
Leioproctus	0.019	0.059	0.326	0.146	0.156	0.912
Drone fly	0.017	0.044	0.387	0.293	0.000	0.931
Orange Hoverfly	0.016	0.045	0.362	0.220	0.000	0.948
Other Syrphidae	0.012	0.045	0.273	0.366	0.000	0.962
Brown Blow fly	0.008	0.030	0.271	0.098	0.031	0.971
Long tongue bumble	0.008	0.045	0.170	0.000	0.156	0.979
Blue Muscid	0.005	0.025	0.201	0.098	0.000	0.984
Bronze thorax fly	0.004	0.030	0.134	0.000	0.031	0.989
Common House fly	0.002	0.014	0.157	0.049	0.000	0.991
Tabanid	0.002	0.012	0.155	0.024	0.000	0.993
Ginger Blister fly	0.001	0.009	0.156	0.024	0.000	0.995
Other Tachinidae	0.001	0.009	0.156	0.024	0.000	0.996
Black Soldier fly	0.001	0.009	0.156	0.024	0.000	0.998
Yellow ad	0.001	0.007	0.157	0.024	0.000	0.999
Robber fly	0.001	0.005	0.157	0.024	0.000	1.000
NZ Blue Blow fly	0.000	0.000	NaN	0.000	0.000	1.000
Euro Blue Blow fly	0.000	0.000	NaN	0.000	0.000	1.000
Grey-black tachinid	0.000	0.000	NaN	0.000	0.000	1.000
Three lined Hoverfly	0.000	0.000	NaN	0.000	0.000	1.000
Other beetle	0.000	0.000	NaN	0.000	0.000	1.000
Cabbage white	0.000	0.000	NaN	0.000	0.000	1.000
Other Lep	0.000	0.000	NaN	0.000	0.000	1.000
Hyaeus	0.000	0.000	NaN	0.000	0.000	1.000
Other wasp	0.000	0.000	NaN	0.000	0.000	1.000
Green hoverfly	0.000	0.000	NaN	0.000	0.000	1.000

Contrast: *Ozothamnus leptophyllus - Kunzea serotina*

	average	sd	ratio	ava	avb c	umsum
Black Hoverfly	0.248	0.208	1.194	4.732	3.0000 0	0.318
Lasioglossum	0.124	0.144	0.857	1.634	1.1875 0	0.476
Green soldier fly	0.084	0.107	0.789	1.268	0.7500 0	0.584
Other Muscid	0.063	0.095	0.669	1.073	0.1250 0	0.665
Leioproctus	0.039	0.107	0.367	0.146	0.6875 0	0.715
Striped thorax fly	0.033	0.090	0.373	0.463	0.1250 0	0.758
Honey bees	0.029	0.063	0.457	0.171	0.4375 0	0.794
Blue Blow fly	0.023	0.038	0.609	0.439	0.1250 0	0.824
Green Blow fly	0.020	0.043	0.470	0.366	0.0625 0	0.850
Drone fly	0.019	0.037	0.518	0.293	0.1250 0	0.874
Other Calliphorid	0.016	0.051	0.312	0.317	0.0000 0	0.894
Other Syrphidae	0.015	0.045	0.342	0.366	0.0625 0	0.914
Orange Hoverfly	0.015	0.035	0.434	0.220	0.0625 0	0.934
11 spot lady	0.015	0.039	0.384	0.220	0.0000 0	0.953
March fly	0.010	0.027	0.361	0.073	0.1250 0	0.965
Brown Blow fly	0.006	0.025	0.238	0.098	0.0000 0	0.973
B. terrestris	0.005	0.021	0.250	0.146	0.0000 0	0.979
Blue Muscid	0.004	0.022	0.201	0.098	0.0000 0	0.985
Tabanid	0.004	0.014	0.284	0.024	0.0625 0	0.990
Common House fly	0.002	0.013	0.157	0.049	0.0000 0	0.993
Ginger Blister fly	0.001	0.008	0.156	0.024	0.0000 0	0.994
Other Tachinidae	0.001	0.008	0.156	0.024	0.0000 0	0.996
Black Soldier fly	0.001	0.008	0.156	0.024	0.0000 0	0.998
Yellow ad	0.001	0.007	0.156	0.024	0.0000 0	0.999
Robber fly	0.001	0.005	0.157	0.024	0.0000 1	0.000
NZ Blue Blow fly	0.000	0.000	NaN	0.000	0.0000 1	0.000
Euro Blue Blow fly	0.000	0.000	NaN	0.000	0.0000 1	0.000
Bronze thorax fly	0.000	0.000	NaN	0.000	0.0000 1	0.000
Grey-black tachinid	0.000	0.000	NaN	0.000	0.0000 1	0.000
Three lined Hoverfly	0.000	0.000	NaN	0.000	0.0000 1	0.000
Other beetle	0.000	0.000	NaN	0.000	0.0000 1	0.000
Cabbage white	0.000	0.000	NaN	0.000	0.0000 1	0.000
Other Lep	0.000	0.000	NaN	0.000	0.0000 1	0.000
Long tongue bumble	0.000	0.000	NaN	0.000	0.0000 1	0.000
Hyaeus	0.000	0.000	NaN	0.000	0.0000 1	0.000
Other wasp	0.000	0.000	NaN	0.000	0.0000 1	0.000
Green hoverfly	0.000	0.000	NaN	0.000	0.0000 1	0.000

Contrast: *Carmichaelia australis - Phormium tenax*

	average	sd	ratio	ava	avb cu	msum
Leioproctus	0.368	0.30755 1	.1968 4.	13636 0.	15625 0.	4162.000
Honey bees	0.200	0.17605 1	.1369 1.	18182 1.	71875 0.	6425.000
Lasioglossum	0.132	0.23189 0	.5698 1.	68182 0.	65625 0.	7919.000
March fly	0.049	0.13898 0	.3533 0.	09091 0.	56250 0.	8474.000
Black Hoverfly	0.032	0.08961 0	.3562 0.	09091 0.	28125 0.	8835.000
B. terrestris	0.022	0.07030 0	.3113 0.	00000 0.	28125 0.	9083.000
11 spot lady	0.016	0.04661 0	.3435 0.	09091 0.	06250 0.	9264.000
Blue Blow fly	0.014	0.05916 0	.2316 0.	00000 0.	18750 0.	9419.000
Long tongue bumble	0.009	0.05284 0	.1739 0.	00000 0.	15625 0.	9523.000
Robber fly	0.009	0.04502 0	.1999 0.	04545 0.	00000 0.	9624.000
Other Muscid	0.009	0.05325 0	.1683 0.	00000 0.	09375 0.	9726.000
Other wasp	0.007	0.03583 0	.2046 0.	04545 0.	00000 0.	9809.000
Bronze thorax fly	0.006	0.03568 0	.1552 0.	00000 0.	03125 0.	9871.000
Other Calliphorid	0.005	0.02039 0	.2366 0.	00000 0.	06250 0.	9926.000
Green soldier fly	0.002	0.01120 0	.2157 0.	04545 0.	00000 0.	9953.000
Hyaeus	0.002	0.01120 0	.2157 0.	04545 0.	00000 0.	9980.000
Brown Blow fly	0.002	0.00992 0	.1744 0.	00000 0.	03125 1.	0.000
Green Blow fly	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
NZ Blue Blow fly	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Euro Blue Blow fly	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Blue Muscid	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Common House fly	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Striped thorax fly	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Ginger Blister fly	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Grey-black tachinid	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Other Tachinidae	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Drone fly	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Orange Hoverfly	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Three lined Hoverfly	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Black Soldier fly	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Other Syrphidae	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Tabanid	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Other beetle	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Cabbage white	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Yellow ad	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Other Lep	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000
Green hoverfly	0.000	0.000	NaN 0.	00000 0.	00000 1.	0.000

Contrast: *Carmichaelia australis - Kunzea serotina*

	average	sd	ratio	ava	avb cum	sum
Leioproctus	0.298	0.25596 1	.1631 4.	13636 0.	6875 0.3	195.000
Black Hoverfly	0.205	0.22032 0	.9292 0.	09091 3.	0000 0.5	392.000
Lasioglossum	0.156	0.21691 0	.7180 1.	68182 1.	1875 0.7	63.000
Honey bees	0.098	0.15619 0	.6280 1.	18182 0.	4375 0.8	116.000
Green soldier fly	0.074	0.11651 0	.6383 0.	04545 0.	7500 0.8	914.000
March fly	0.018	0.06105 0	.3024 0.	09091 0.	1250 0.9	112.000
Striped thorax fly	0.013	0.05626 0	.2385 0.	00000 0.	1250 0.9	256.000
Blue Blow fly	0.010	0.02901 0	.3558 0.	00000 0.	1250 0.9	367.000
Other Muscid	0.010	0.02917 0	.3490 0.	00000 0.	1250 0.9	476.000
Drone fly	0.009	0.02549 0	.3581 0.	00000 0.	1250 0.9	574.000
11 spot lady	0.007	0.02697 0	.2725 0.	09091 0.	0000 0.9	653.000
Robber fly	0.006	0.02998 0	.2006 0.	04545 0.	0000 0.9	718.000
Green Blow fly	0.006	0.02476 0	.2413 0.	00000 0.	0625 0.9	782.000
Other Syrphidae	0.006	0.02476 0	.2413 0.	00000 0.	0625 0.9	846.000
Other wasp	0.005	0.02553 0	.2045 0.	04545 0.	0000 0.9	902.000
Orange Hoverfly	0.004	0.01576 0	.2487 0.	00000 0.	0625 0.9	944.000
Tabanid	0.003	0.01232 0	.2514 0.	00000 0.	0625 0.9	977.000
Hyaeus	0.002	0.00989 0	.2152 0.	04545 0.	0000 1.0	0.000
Brown Blow fly	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
NZ Blue Blow fly	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
Euro Blue Blow fly	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
Bronze thorax fly	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
Other Calliphorid	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
Blue Muscid	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
Common House fly	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
Ginger Blister fly	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
Grey-black tachinid	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
Other Tachinidae	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
Three lined Hoverfly	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
Black Soldier fly	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
Other beetle	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
Cabbage white	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
Yellow ad	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
Other Lep	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
Long tongue bumble	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
B. terrestris	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000
Green hoverfly	0.000	0.000	NaN 0.	00000 0.	0000 1.0	0.000

Contrast: *Phormium tenax - Kunzea serotina*

	average	sd	ratio	ava	avb cu	msum
Black Hoverfly	0.245	0.248	0.9886 0	.28125 3	.0000 0.	2745.000
Honey bees	0.173	0.147	1.1770 1	.71875 0	.4375 0.	4682.000
Lasioglossum	0.136	0.164	0.8288 0	.65625 1	.1875 0.	6209.000
Green soldier fly	0.095	0.146	0.6508 0	.00000 0	.7500 0.	7272.000
Leioproctus	0.060	0.146	0.4094 0	.15625 0	.6875 0.	7943.000
March fly	0.039	0.110	0.3600 0	.56250 0	.1250 0.	8385.000
Blue Blow fly	0.024	0.062	0.3911 0	.18750 0	.1250 0.	8658.000
B. terrestris	0.021	0.067	0.3178 0	.28125 0	.0000 0.	8895.000
Other Muscid	0.020	0.058	0.3513 0	.09375 0	.1250 0.	9123.000
Striped thorax fly	0.017	0.070	0.2452 0	.00000 0	.1250 0.	9314.000
Drone fly	0.011	0.030	0.3656 0	.00000 0	.1250 0.	9436.000
Long tongue bumble	0.009	0.051	0.1762 0	.15625 0	.0000 0.	9538.000
Green Blow fly	0.007	0.030	0.2476 0	.00000 0	.0625 0.	9621.000
Other Syrphidae	0.007	0.030	0.2476 0	.00000 0	.0625 0.	9704.000
11 spot lady	0.007	0.030	0.2362 0	.06250 0	.0000 0.	9783.000
Bronze thorax fly	0.005	0.031	0.1603 0	.03125 0	.0000 0.	9838.000
Other Calliphorid	0.005	0.019	0.2424 0	.06250 0	.0000 0.	9890.000
Orange Hoverfly	0.005	0.018	0.2531 0	.00000 0	.0625 0.	9941.000
Tabanid	0.004	0.014	0.2548 0	.00000 0	.0625 0.	9981.000
Brown Blow fly	0.002	0.010	0.1765 0	.03125 0	.0000 1.	0.000
NZ Blue Blow fly	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Euro Blue Blow fly	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Blue Muscid	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Common House fly	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Ginger Blister fly	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Grey-black tachinid	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Other Tachinidae	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Three lined Hoverfly	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Black Soldier fly	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Robber fly	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Other beetle	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Cabbage white	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Yellow ad	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Other Lep	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Hyaeus	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Other wasp	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000
Green hoverfly	0.000	0.000	NaN 0	.00000 0	.0000 1.	0.000

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